Electric Distribution System Planning with DERs – High-level Assessment of Tools and Methods

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PNNL-28138

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Executive Summary

Electric distribution system planning supports investment decisions and operations strategies. It is a broad subject with many facets. The increasing number of distributed energy resources (DERs)[1] connected to the grid is changing how utilities perform their distribution planning process. The adoption of DERs is based on a combination of several factors including state policy incentives, favorable economics, consumer preferences, and the provision of reliable and resilient power, for example through the application of energy storage and microgrids. This report assesses the planning tools and methods available for utilities performing distribution system planning with DERs and identifies the gaps that exist, as well as future functionality that will be needed.

The report is part of a larger ongoing effort through the U.S. Department of Energy's Grid Modernization Laboratory Consortium and is a companion to the report, *Summary of Electric Distribution System Analysis with a Focus on DERs*, which was published in April 2017.[i] Information in this report can assist stakeholders (including utility personnel, regulatory bodies, technology manufacturers, product and software vendors, think tanks, and research organizations) as they plan for and begin to participate in integrated distribution system planning activities, regulatory proceedings, or tool development.

Growing numbers of DERs on the distribution grid are increasing the speed of grid dynamics, which in turn requires better grid observability (sensing and measurement) and faster controls. This process requires higher-performance communications networks with more complex interface requirements. Some early-adopter states are taking a methodical approach for conducting a high-level assessment of needs that accounts for the structure of the grid, and tools needed to help prioritize and evaluate options. The increasing adoption of DERs is changing utilities' distribution system planning processes. Utilities must account for increased uncertainty due to DERs and need to evaluate potential future scenarios. To remain flexible and adaptable to changing conditions and technology development, **scenario analysis, granular forecasting, and options analysis are becoming increasingly important in integrated distribution system planning.**

Utilities need accurate, granular data to develop system models, validate results, and perform analysis. Collecting the data needed for integrated distribution system planning analysis means utilities must install new measurement, sensing, and communication technology, as well as capture ongoing field changes to make sure that electronic models are up to date and represent the current state of operation. Obtaining the necessary data can be a significant challenge for utility planners and other decision makers, and it can require significant time and cost. Without granular, accurate data of the distribution system all the way to the premise level, analysis is limited, and results can be inaccurate. Therefore, **it is essential that utilities and regulators make strategic, targeted data collection a priority including identifying data gaps**

[1] The National Association of Regulatory Utility Commissioners (NARUC) defines a DER as "a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load. Examples of different types of DER include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE)." NARUC*, Distributed Energy Resources Rate Design and Compensation*, 2016.

associated with specific analyses of interest and developing strategies for filling those gaps. This can be done in a proportional manner according to need (spatially and/or temporally).

The more advanced analysis also necessitates new tools and approaches, and it requires new expertise to perform the analysis. Forecasting the number of future DERs deployments is important for distribution system planning, but it is challenging in part because DER deployment is dependent on policies and tariffs, which can be influenced by the distribution system planning process itself. While there are emerging tools that can provide utilities with granular load and DER forecasts, a **tool capable of evaluating different DER deployment scenarios and policies and then automatically updating projections based on actual deployment patterns would be helpful for utility planners and regulators.**

Power flow analysis plays a key role in traditional distribution system operation and planning, but it is evolving to consider changing operating conditions, as more DERs are connected to the distribution system. DERs create more variable supply and demand, so it is no longer enough for utility planners to consider only peak-load conditions at periodic instances in time. Utilities are beginning to utilize time series power-flow analysis (TSPFA) to understand the impact of DERs. TSPFA is a time-series grid simulation composed of multiple steady-state power-flow calculations with user-defined time step sizes between each calculation. TSPFA at short time steps can require significant computational times and iterative solvers. **While some utilities do not have the granular system data necessary for TSPFA, other utilities do not have the expertise or computing power.** In research domains, a variety of proposed “fast TSPFA” approaches have emerged, but more work is needed.

Several tools are needed that could assist utility planners, including commercial tools that move beyond hosting capacity screens and automatically generate solutions when hosting capacity or interconnection analyses identify an issue. Utilities have numerous options for mitigating issues, including controls, capacitors, battery storage systems, reconfiguring circuits, or demand-side solutions, and these can be used in a multitude of combinations. Traditional distribution system analysis tools (CYME, Synergi, Milsoft), as well as research tools (GridLAB-D and OpenDSS), can be used to manually perform analysis and explore different solutions. But no tools exist that can provide an automated review and assess potential solutions to interconnection studies or hosting capacity analyses and then recommend the best resource or combination of resources to meet system needs. A tool that could automate this process and help utilities identify and evaluate options would allow for a quicker assessment of solutions and could inform conversations with developers and customers.

More robust tools are needed that can simulate distribution systems with multiple devices, such as smart inverters and energy storage, simultaneously operating autonomously. Tools are needed that can co-simulate the distribution and transmission systems, as well as DER, under different scenarios to determine reliability, protection, and the suitability of non-wires alternatives. Although tools exist—such as DER-CAM, ReOpt, and HOMER—that optimize DERs at the campus or microgrid levels, they do so based on balance of energy equations rather than engineering power flow analysis. **Engineering tools that incorporate power flow analysis are needed for selecting optimum type, sizing, and placement of DERs at the distribution system scale**.

Table S.1 contains a summary of key gaps and challenges for distribution system planning with DERs.

Table S.1. Summary of Gaps and Challenges for Distribution System Planning with DERs

Area	Challenges
Data and feeder models	• Developing required data sets to conduct detailed analyses • Managing the sheer amount of data and daily configuration changes • Breaking down data silos at utilities • Standardizing data formats between applications • Making sure validated and calibrated feeder models are kept up to date
Grid architecture	• Capabilities to readily determine grid service requirements for different system configurations, e.g., microgrids and other non-traditional topologies • Tools for planning an observability strategy and/or sensor allocation plan • Tools for integrating communication networks and distribution circuit planning • Tools that plan for the use of markets and market-like mechanisms for DER integration and coordination
Projecting DERs	• Commercial/mature tools that project customer adoption rates of DERs taking into consideration policies and existing deployment rates
Time-series power flow analysis (TSPFA)	• Streamlined methods for conducting TSPFA to reduce computation times • Dynamic and transient analysis capabilities for assessing frequency and inertia impacts of DERS
Hosting capacity analysis and interconnection studies	• Tools that identify best resource combinations (including controls, capacitors, circuit reconfiguration, storage, or demand-side solutions) to mitigate hosting capacity exceedances • Analysis associated with protection coordination • Real-time updating and semi-automated interconnection request evaluation
Characterizing locational value, including identifying non-wires alternatives	• Tools that automatically provide a set of appropriate non-wires alternatives given system needs • Tools that identify value based on DER physical impact assessments • Resilience, reliability, & power quality impact characterizations of DERs • Commercial tools that characterize impacts of DERs with full smart inverter and/or storage functionality
Co-simulation and advanced optimizations	• Improved usability and scalability of distribution/transmission co-optimization tools • Tools for optimizing the type, number, size, and location of DERs in distribution systems based on engineering analysis • Capability to characterize transmission and distribution integration impacts and impacts of advanced technologies such as demand response, electrification, and energy storage
Equipment and technology-specific gaps	*Smart Inverters* • Tools that model all smart inverter functions • More robust tools to simulate many smart inverters operating independently • Smart inverter manufacturer information for tool development *Battery Storage* • A battery valuation tool that addresses multiple use cases and co-optimizes across the bulk, distribution, and customer systems, including ancillary services • Distribution scale tools that support the sizing and location of battery systems • Manufacturer battery storage information for tool development *Flexible loads* • Incorporation of market-activated flexible loads and the associated short-run marginal costs or other price signals into commercial tools *Microgrids* • Real microgrid data for tool testing and development • Dynamic modeling of microgrids in commercial tools or commercial co-simulation tools that link microgrid tools with traditional distribution system analysis tools *Electric Vehicles (EVs)* • Specific EV manufacturer information for modeling • Commercial tools that support projecting EV adoption and charging behavior

Acronyms and Abbreviations

AMI	Advanced metering infrastructure
AS	ancillary services
CAM	Customer Adoption Model
CPUC	California Public Utilities Commission
DER	distributed energy resource
DERAC	DER Avoided Cost Calculator
DOE	U.S. Department of Energy
E3	Environmental Economics, Inc.
EPRI	Electric Power Research Institute, Inc.
EV	electric vehicles
FINDER	Financial Impacts of Distributed Energy Resources
FNCS	Framework for Network Co-simulation
GIS	geographic information system
GMLC	Grid Modernization Laboratory Consortium
HELICS	Hierarchical Engine for Large-scale Infrastructure Co-simulation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IESM	Integrated Energy System Model
IOU	Investor-Owned Utilities
LBNL	Lawrence Berkeley National Laboratory
LNBA	Locational Net Benefits Analysis
MCSS	marginal cost of services studies
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NWA	non-wires alternatives
PNNL	Pacific Northwest National Laboratory
PSLF	Positive Sequence Load Flow
PSS/E	Power System Simulator for Engineering
PV	photovoltaic
ROMDST	Remote Off-grid Microgrid Design Support Tools
RPS	renewable portfolio standards
SAM	System Advisor Model
T&D	transmission and distribution
TSPFA	time series power-flow analysis

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1.0 Introduction

Electric distribution system planning supports investment decisions and operations strategies. It is a broad subject with many facets. This report focuses on distribution system planning with distributed energy resources (DERs) and assesses the capability of current planning tools and methods that can identify needed system requirements that will make certain of reliable and effective operations with DERs. As utilities face increasing adoption levels of DERs, more granular analysis (temporally and spatially) becomes necessary, which is changing how utilities conduct distribution planning. Factors that impact distribution planning include cost, safety, reliability and resilience, operational efficiency, customer satisfaction, aging infrastructure, and growing adoption of renewable and other distributed resources.

This report provides an overview of the tools available to assist utility planners in performing various analyses; the gaps that are not currently addressed by existing tools; and new emerging areas of analysis. The tools include computer models and software, as well as other analytical aids and practices that support distribution planning. DERs include (1) generation sources located on the distribution system, such as solar photovoltaic (PV) systems, wind generators, hydro generation, geothermal generators, natural gas, and diesel generators; (2) battery electric storage systems; (3) demand response and transactive energy systems; and (4) energy efficiency technologies.

As part of a larger, ongoing effort by the U.S. Department of Energy's (DOE's) Grid Modernization Laboratory Consortium (GMLC), the goal is to address analytical tools and methods to support integrated electric distribution system planning. This report is a companion to *Summary of Electric Distribution System Analysis with a Focus on DERs*, which was published in April 2017.[ii] While the 2017 report focused on types of distribution system analyses needed to understand the impacts of DERs, this report focuses on tools and methods used in distribution system planning.

While the analysis for this report made an effort to assess the tools and approaches available to industry, the tools evaluated represent the capabilities available and may not be an exhaustive list of all commercially available tools. This information can assist stakeholders (including utility personnel, regulatory bodies, technology manufacturers, product and software vendors, think tanks, and research organizations) as they plan for and begin to participate in more detailed distribution system planning activities, regulatory proceedings, or tool development and activities that include DERs.

2.0 Growing Importance of Distribution Planning

The purpose of electric distribution system planning is to assess needed physical and operational changes to the local grid in order to maintain safe, reliable, and affordable service. Distribution planners must consider a vast number of factors and constraints as they work to forecast new growth, serve loads, and maintain reliability.

While electric utilities have always engaged in some type of electric distribution system planning, distribution planning is becoming increasingly complex and is receiving more attention due to the changing nature of the grid, increased interdependencies, and growing numbers of customer-owned resources.

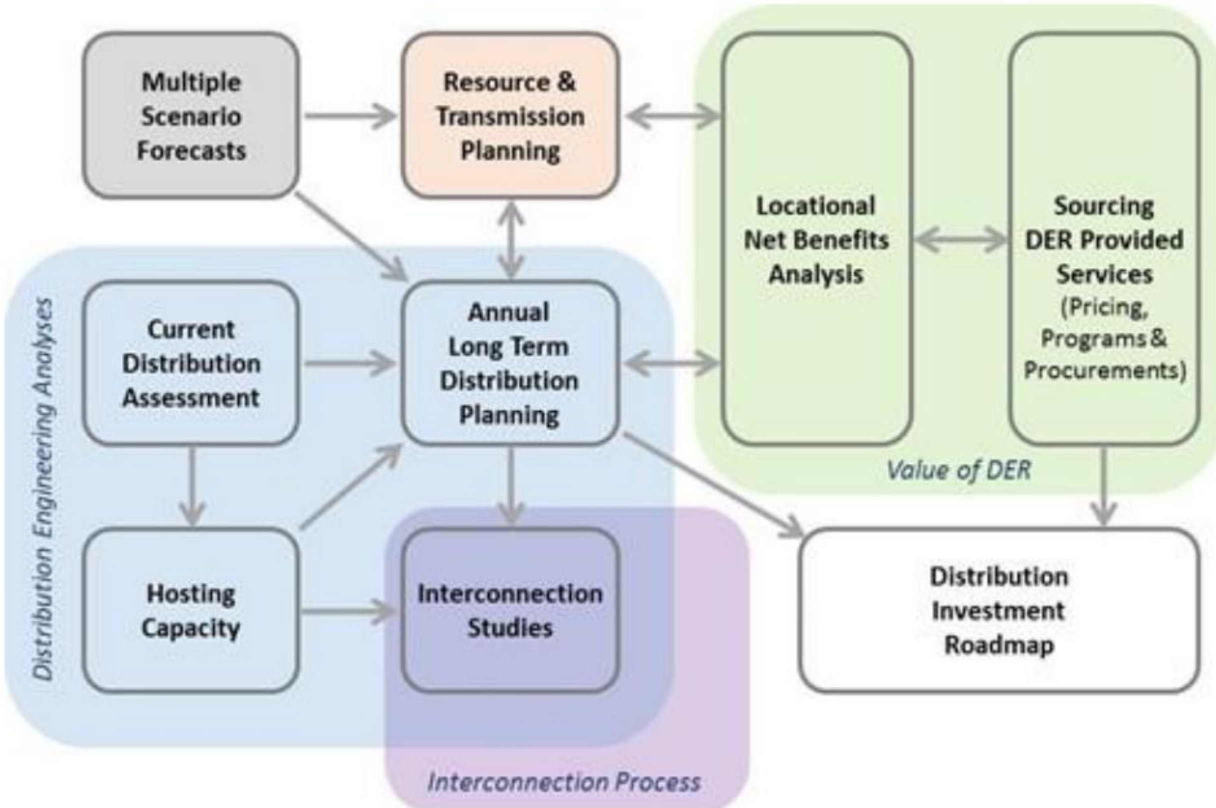
Traditional distribution system planning has a short time horizon of one to three years and limited involvement by state utility regulators; however, the focus is shifting to longer time horizons and a more holistic or integrated process, with greater transparency and more involvement by regulators and other energy stakeholders. It is becoming a more collaborative process whereby stakeholders can provide input and review projections, assumptions, and analysis results in a more structured way.

State policy goals and utility business objectives set the context for distribution system planning and grid investments. In many states, general assemblies, utility regulatory commissions, and other policy-making organizations set specific requirements, mandates, or state goals around reliability and resilience, grid modernization, greenhouse gas emissions, and/or renewable energy targets that can impact utility operations, planning, and procurements. Utility business objectives within the larger regulatory and prudence framework also play an important role in investment decisions.

As a result, a growing number of states and utilities are beginning to consider a comprehensive distribution system planning process to address the costs and benefits of DERs; to reflect the additional choices coming from the customer/third-party domains; to integrate with resource and transmission planning; and to incorporate scenarios that reflect the dynamic and changing nature of the electricity system. Some states use distribution system planning to characterize the ability of the local grid to accommodate DERs and to characterize the location and time-based value of DERs to the grid. Additionally, these comprehensive distribution system planning processes facilitate discussions and input from stakeholders, help to inform state policies, and provide information for other key stakeholders in the state.

Advanced distribution system planning, in contrast to traditional distribution system planning, requires the evaluation of many interdependencies involving different aspects of planning. These interrelationships between planning for system resources, distribution, transmission, and operations are evolving.[iii] Figure 1 illustrates the many components and interactions in integrated distribution planning as defined in a report by Paul DeMartini and ICF for the Minnesota Public Utilities Commission.[iv]

Figure 1. Integrated Distribution System Planning



*This figure was obtained from Paul De Martini of Newport Consulting. See Endnote v.

The interdependencies between the different planning areas introduce new variables and create complexity. In the past, planning only needed to consider one-way power flow and a very limited number of distributed resources. Now, planners must understand the potential for and implications of a significantly larger number of DERs, and they must perform increasingly complex analyses to account for the many variables that can impact future-load and generation requirements. This added complexity necessitates the need for flexible and adaptive approaches to implementing integrated distribution systems. Using real options analysis to design flexibility into utility roadmaps and investment and implementation plans can be valuable for utilities and customers by accounting for unforeseeable technologies and services that are likely to emerge over time. Real option analysis is an alternative approach to resource decision making and may result in greater benefits to the customer than net present value or benefit cost approaches for infrastructure investments that can be undertaken incrementally, such as for grid field devices or communication networks.[v]

Collecting the data needed for integrated distribution system planning analysis means utilities must install new measurement, sensing, and communication technology. The more advanced analysis also necessitates new tools and approaches and requires new expertise to perform the analysis.

To assist with efforts, some utilities are contracting with external vendors or consultants for data collection, management, and analysis. Coordination between these external entities and utility planning operations is challenging. Collecting data and analyzing the necessary areas can lead to additional equipment and overhead costs.

While enhanced distribution planning may be costly due to the additional equipment, manpower, and computing needs, it provides numerous benefits, including an increased and more granular understanding of the costs and benefits of DERs and grid modernization investments, while allowing the utility to accurately assess changing conditions and better evaluate future investments in order to maintain reliability, safety, and affordability. Additional benefits include the following:[vi]

- Establishing the hosting capacity of circuits to indicate the amount of DER that can be managed on a feeder easily, or where interconnection costs will be lower or higher.
- Making hosting capacity data available to inform customers and third parties upfront about areas where DER interconnections would be less likely to impact grid operation, which can help lower development costs.
- Providing information about the value of specific resources or services at various grid locations to guide developers.
- Allowing the utility to proactively identify potential upgrades of circuits that are likely to see DER growth.
- Allowing utilities to develop incentives for customers and third parties so they can understand the locations where DERs would benefit the grid.
- Enabling the evaluation of deferring traditional infrastructure investments through non-wire alternatives that provide specific services at specific locations.
- Helping utilities prioritize solutions and leverage third-party capital investments.
- Informing rates and tariffs.
- Increasing transparency around utility distribution system investments before they are brought to the regulatory body for cost recovery.
- Providing opportunities for meaningful stakeholder engagement, which can improve outcomes.
- Allowing for the consideration of uncertainties under a range of possible futures.
- Supporting the consideration of both traditional and non-traditional supply and demand-side solutions to minimize cost and risk.
- Providing an impetus for the utility to select and implement reasonable cost/risk solutions.
- Supporting emerging participation by consumers and third parties in proposing grid solutions and providing grid services.

3.0 Foundational Elements

Validated and calibrated feeder models with accurate data are foundational to distribution planning and the analyses that support decision-making. Inaccurate data can lead to models that do not accurately reflect operating conditions, which can subsequently lead to overly conservative or inaccurate results. **Therefore, for advanced distribution planning, utilities and commissions need to make *data collection, data management, and maintaining validated and calibrated feeder models priorities.***

3.1 Validated and Calibrated Feeder Models

As the power grid is modernized and more in-depth analysis becomes essential for assessing options and understanding changing usage and generation patterns, utilities need detailed, computer-based models of their electric distribution systems. This requires utilities to understand and electronically document their systems, including customer connections, in a more detailed fashion, which can take significant time and effort. Utilities must track and document the location of specific equipment and its connections, including which phase is connected at a specific location. This is very specific information that is not necessarily needed for day-to-day operations but is essential for analysis and confirming accurate results. As crews manage, repair, and operate the grid, numerous field changes can take place. Making sure these field changes are reflected in the computer representation can require new asset management approaches for field crews.

Constructing models so they represent incidents and power systems phenomena to a sufficient degree of confidence requires a large amount of data, which, depending on the utility, may involve hundreds of substations that serve hundreds to thousands of different distribution feeders. It includes gathering information such as which phase of the transformer a customer is connected to, as well as elements such as asset health and stress accumulation, thermal and other environmental states, and the states of grid-connected assets, for example a third-party or customer-owned DER, including energy storage. One issue though is that the data needed for modeling feeders, loads, and DERs is not always available. For example, few utilities have collected enough information to measure minimum load at the feeder level, which is an important consideration with large numbers of DERs connected to a system.[vii] Adding to the difficulty of constructing workable models is that not all the data can be measured directly; in some cases, it must be calculated using other measurements, then possibly combined with models of the physical systems under consideration.

To determine the degree to which the feeder model can provide an accurate representation of what is taking place in the system, it is important to validate the model with real operational data. If a model is not validated, ideally by comparing modeled results with measured data, the model can produce inaccurate results that can lead to reliability and power-quality problems or excessive conservatism and unnecessarily high customer interconnection costs. Challenges associated with developing accurate and validated distribution system models include limited visibility into distribution systems, a lack of knowledge of minimum load conditions, and imprecise knowledge of impedances and topology.[viii] In addition, distribution systems configurations can change daily, so documenting changes can require new utility processes that can be difficult and costly.

Some commercial tools can help fill gaps in models and help utilities piece together a system model from incomplete or incompatible data sets, but this leads to less-than-accurate results because analyses conducted on distribution systems are only as good as the feeder models and data. Therefore, it is important that data gathering and accuracy and regular model updates be made a priority. Not a lot of research has been conducted on understanding where estimations work well versus where actual data should be prioritized when real data is not available. This is a gap.

3.2 Accurate and Granular Data

Distribution system analysis for planning is used to make sure the system can handle the worst-case scenario. Where generation is constant, or fully dispatchable and always available, the worst case is the peak load. However, when both demand and supply vary over time, the worst-case scenario is not as easily determined—it might be peak load or minimum load conditions, or somewhere in between. This is where time-series analysis (discussed in the next section) and granular load and supply data are required to determine the worst-case scenario conditions that the system must be designed to handle. Site-specific data, rather than aggregate data, are helpful, as are detailed load profiles and generation profiles of future expansions. For example, for distribution system planning, the projected usage profile for a planned community electric vehicle charging station would be needed. Utilities are not used to developing this type and granularity of data. This is a gap.

Accurate and granular data for distribution system planning is a challenge for several reasons. One reason is the sheer amount of data—some utilities have thousands of distribution feeders—and the time, effort, and attention to detail required to collect the data and capture the field configuration changes. Additionally, in the past, distribution system planning did not require a granular analysis of the distribution circuits. However, changing technology, growing DERs, and impacts from distribution that roll up to transmission require utilities to begin collecting data and confirming accuracy of data they did not need in the past. This can create significant challenges, be time consuming, and lead to significant costs.

Data Types Useful for Distribution Planning with DERS

- Granular (in time and space) load growth projections
- System capacity planning studies—from distribution transformer to bulk system sub-transmission
- Existing and projected distributed generation deployment and production by location and time of day and year
- Line loss studies
- System reliability studies (including voltages, protection, phase balancing)
- System-wide and location-specific cost information
- System-wide and location-specific peak demand growth rates
- Embedded and marginal cost of service studies

Collecting the data can require sensors and/or site visits, supervisory control and data acquisition, data processing, and data storage. New sensing devices are being developed that can collect additional types of data, which will help improve model accuracy, but will also pose challenges to data collection and increase the amount of computing power needed to process the data. However, these data are not free, and utilities have many competing priorities when it comes to budget allocation, along with pressure to keep customer rates low. This makes data prioritization important. Tools that support prioritizing data collection, given specific desired outcomes, are a gap.

There are organizational challenges also associated with data. Data is often siloed in different departments within the utility and may be owned by several entities inside and outside the distribution utility. Relevant data may come from customer information systems, billing systems associated with metering electric services, and records of participation in utility programs, such as demand response programs. To work around silos, vendors usually supply import and export routines to get the data out of applications so that they can use it. The mechanisms to do this can be clunky and cumbersome and can create issues because they must be updated when data formats are revised. Having common formats (e.g., the Common Information Model, which has been adopted by the International Electrotechnical Commission for power-system data exchange[2]) can help, but they have their own challenges with version upgrades. For example, CIM started as a transmission-level model for control centers but has been updated to include distribution system concepts and more recently DER models. Issues such as privacy and protection of information about customer-owned devices and their data are being wrestled with by vendors of new technology, utilities, and those working directly with customers. In addition, new participants in the energy data ecosystem may not see the business value in participating in common information models and making their products conform to standards.

Additional demographic trend data from external sources—including building developers, DER equipment, and service providers—can yield insights for planning purposes and create challenges for the utility to consolidate and monitor.

Another challenge is that new analysis areas require new data sets. As analysis moves from static snapshots in time to more variable and dynamic analysis, this will require additional information. Time-series power-flow analysis (TSPFA), which is discussed later in this report, is a more in-depth analysis type that an increasing number of utilities are using. Through TSPFA, utilities can better understand the impacts on the electric system of DER and demand variability over time. Data sets needed for TSPFA are even greater than those for static system snapshots. Lack of data can be a limiting factor.

Distribution system planning efforts would benefit from data standardization. Different data formats exist that are entrenched in existing applications. Proprietary models store data in proprietary formats, which are inaccessible to other analysis tools. A national-level effort would be helpful on data standardization approaches and open-source data sharing and accessibility models. A standard is needed that cuts across asset management, asset demographics, and power flow. Without data standardization, tool developers are limited and constrained in what they can do because they cannot access data required to perform needed analyses without significant effort that must be customized for each utility and their unique systems and applications.

CIM and MultiSpeak are two existing data standardization formats used in the energy sector. Many organizations have been or currently are engaged in conversations about energy data standardization. Existing efforts include IEC Technical Committee 57, MultiSpeak Advisory User Group, Utilities Communication Architecture International Users Group, Smart Electric Power Alliance, and the Institute of Electrical and Electronics Engineers Standards Association 2030. A gap relative to common data formats for distribution system planning is an industry-wide convening/conversation around the key issues; ultimately, a game plan to address data standardization is needed but does not currently exist. A surgical path forward would be to specifically identify the data that are locked up that need to be exchanged to support distribution system planning. This could start with convening those entities who are currently experiencing the problems to define the specific key issues. From there the standards landscape could be

[2] For more information on the Common Information Model as part of the International Electrotechnical Commission see https://www.iec.ch/smartgrid/standards/

assessed along with a review of organizations to identify the best to work with to address the issues.

Where common data formats already exist, there are opportunities for improvement. The sciences of information technology and semantic technology come into play with developing or improving data standardization. Cybersecurity issues can accompany data standardization; therefore, data cybersecurity must be addressed concurrently.

Efforts to collect and make sure the accuracy of data can be time consuming, can incur significant costs, and may require new processes. But, as utility planners and other decision makers increasingly utilize models and analysis whose results depend on specific, accurate granular distribution system data, it is essential to prioritize data collection and accuracy, identify data gaps, and develop strategies for filling data gaps.

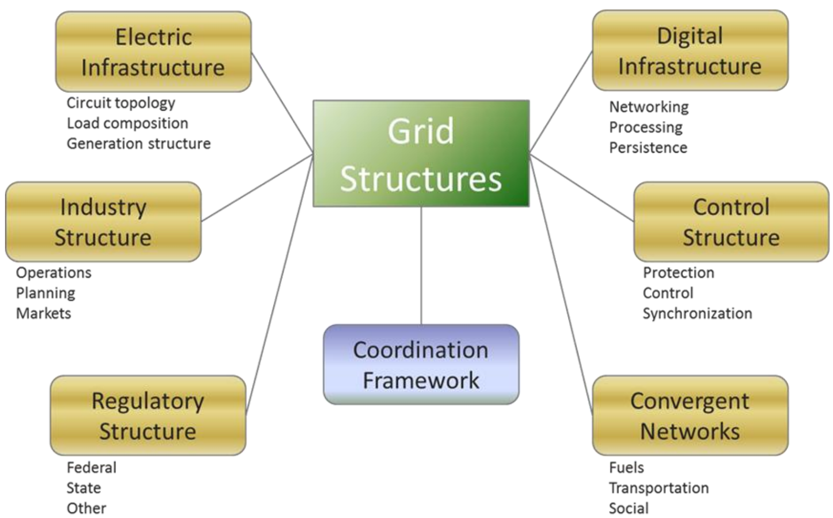
3.3 Grid Architecture

A system architecture is an abstract depiction of a system, consisting of black box components, structure, and externally visible properties. It enables reasoning about a system's structure and behavior; helps to manage system complexity; facilitates communication among stakeholders (internal and external); manifests earliest design decisions/constraints; helps to identify gaps in theory, technology, organization, and regulation; enables prediction of system qualities; and helps to identify and define interfaces and platforms. It is the highest-level depiction of a complex system.

Grid architecture is the application of system architecture and certain related disciplines to the electric power grid. In this discipline, the grid is viewed as a network of structures (a set of structures that are highly interconnected), as shown in .

Figure 2.

Figure 2. Network of Structures Model for the Grid



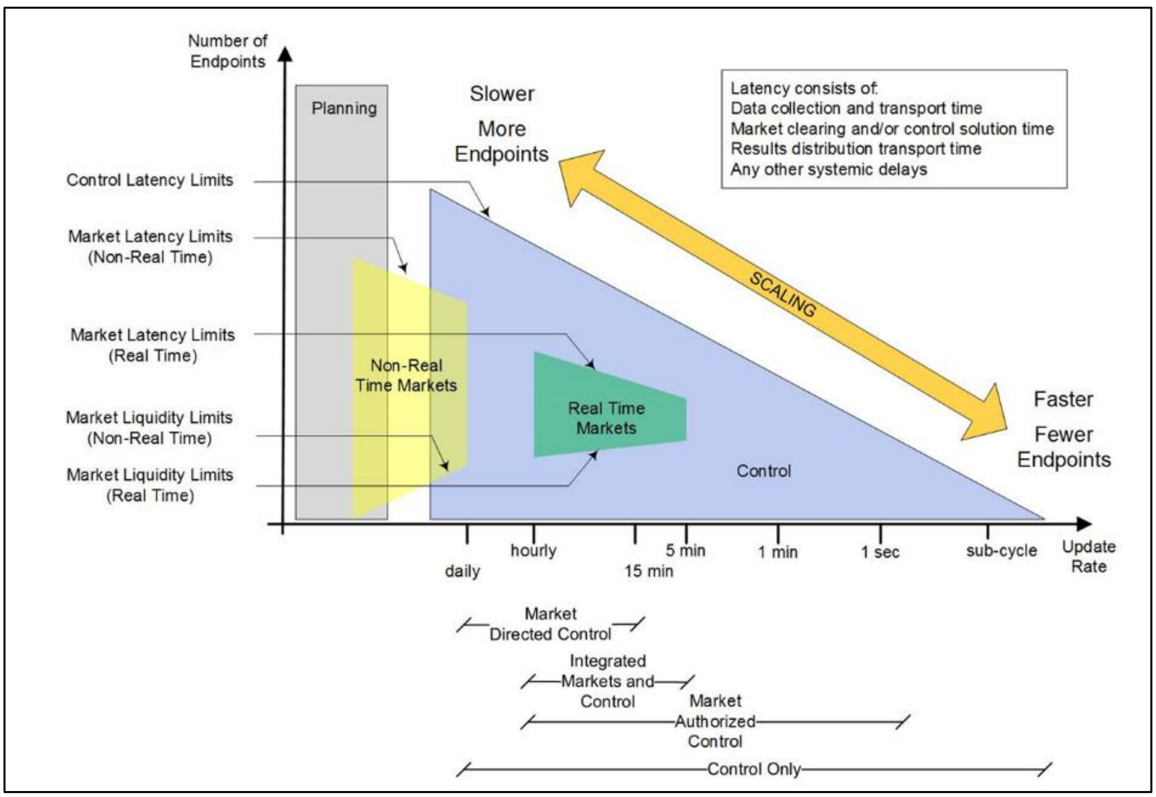
The distribution grid structure is changing as a result of external forces and new technology options that can fundamentally change grid configurations, such as customer-owned DERs.

Generation, for example, is being split into both transmission-connected bulk generation and distribution-connected distributed generation. These emerging trends have systemic implications that impact how utilities will need to plan in the future. Given the level of uncertainty and the number of new options available for grid operations, investment strategies need to incorporate the flexibility to "defer, stage, expand, or abandon" investments under different possible scenarios. Utilities need to design flexibility into the system as part of the planning process and create options that can be incorporated into the system architecture.[ix]

The penetration of DER is increasing the speed of grid dynamics, which, in turn, requires more sensing and measurement for better grid observability and faster, more direct system controls. This in turn requires higher-performance communications networks with more complex interface requirements, which immediately illuminate the gap that tools and methods do not exist for planning a distribution grid observability strategy or for creating a sensor allocation plan together with a communication strategy for the distribution system. There is, however, a significant amount of research in meter placement for state estimation, but the tools for planning a communication network do not integrate with distribution circuit planning and do not have adequate methods for taking into account grid sensor allocation and control system requirements.

In addition, planning has a significant connection to markets and controls for the grid.[x] As illustrated in Figure 3, there is essentially a spectrum of functions that encompasses planning, market, and controls. As planning advances into the future, these connections need to be more clearly and explicitly taken into consideration, particularly as related to integrated transmission and distribution (T&D) system planning.

Figure 3. Planning/Markets/Control Spectrum[xi]



Another gap is the lack of capabilities to readily determine grid service requirements for different system configurations. This is particularly important in efforts to modify grid structures, such as microgrids, to protect critical infrastructure with systems that can island or with various battery storage applications. In addition, existing planning tools do not have the means to evaluate the use of markets and market-like mechanisms for DER integration and coordination, nor are any available that can assess the trade-off between using markets, using controls, or using market-control hybrid methods for grid management. However, some transactive energy platforms are attempting to address this.

All planning occurs in the context of a grid architecture, whether this is recognized and documented or not. Increasingly, planning must simultaneously account for multiple grid structures, and operators will need to incorporate some knowledge of grid architecture concepts and actual grid architectural structures (as they exist and as they will exist) into the planning method and processes.

4.0 Analysis Areas for Planning with DERs

Distribution system planning that considers the benefits and impacts of DERs requires additional analysis. This section describes the current and emerging analysis areas for distribution system planning with DERs, the tools available to perform the analysis, the gaps that currently exist, and the functionality that will be needed in the future.

4.1 DER and Load Projections – Multiple-Scenario Forecasts

Understanding the current and potential future customer loads is fundamental to distribution system planning and is necessary for evaluating future system constraints and investment alternatives. DER adoption rates can have a significant impact on future-load projects; however, projecting the impact of customer-owned DER and future adoption that could offset demand can be difficult and can introduce additional uncertainty into the distribution planning process. Therefore, distribution system planners must consider both future-load forecasts and DER projections.

Traditional load-growth projections are commonly included in current distribution system analysis tools; however, no traditional distribution system analysis tools have the capability to endogenously predict DER growth and net-load profiles.

Even understanding the baseline or current DER energy production on a system is difficult, as utilities do not have visibility (or specific data) on the energy produced by customer-owned systems. DERs often reduce net loads on feeders and can mask the true nature of the load on the circuits because most distributed generators are located behind the customer meter so that the utility is unaware of its output and sees its impact only through reduced demand. This can contribute to increased load-forecasting errors because the utility is unaware of the magnitude of the distributed generation that is present.

Developing multi-scenario forecasts for load and DER adoption can help utilities better understand the potential effects of DERs on distribution system load and can help account for uncertainty that these systems introduce.[xii] By evaluating multiple scenarios and accounting for different load and DER possibilities, utilities can identify potential issues and evaluate mitigation strategies and options. Minimum load becomes much more important with DERs because some distribution system equipment is not designed for reverse power flow. If the generation produced on the distribution system is greater than the minimum load, reverse power flow can occur.

As more DERs enter the picture (PV, storage, electric vehicles [EVs], demand response), the utility may need to utilize different models to determine the component parts of the net-load forecast. Multiple-scenario forecasts can include a business-as-usual case; scenarios with varying DER growth projections;[3] (e.g., different growth rates each for energy efficiency, demand response, combined heat and power, distributed generation, EVs, and storage); scenarios that reflect cost decreases for certain DERs; scenarios that are reflective of specific policies; (e.g., carbon/sustainability scenarios); and scenarios that explore different energy service provider landscapes, such as a high community choice aggregation scenario.[xiii]

[3] For example, Southern California Edison and Pacific Gas & Electric developed and explored trajectory, high growth, and very high growth scenarios for DER.

While, historically, annual peak load by feeder was the key metric for distribution system planning, there is a move to more granular load forecasts in time and space. Some utilities are moving toward annual hourly load forecasts by feeder and/or by customer class. LoadSEER™ is a commonly used tool for granular scenario load forecasting. More granular load forecasts and usage profiles, combined with granular DER projections, allow utility planners to model and better understand the net loads requirements under different scenarios.

While load forecast approaches have been well established, the methodologies for forecasting DER adoption rates are still under development. Effectively forecasting DER adoption requires estimation of the following elements:[xiv]

1. Technical potential: Estimation of amount of DER capacity that can fit within the physical constraints at each customer site.
2. Economic potential: Estimation of amount of cost-effective DER capacity based on a specified financial metric at each customer site.
3. Customer adoption: Estimation of the actual customer adoption of DER.

There are various methodologies and tools available to complete elements 1 and 2, including the National Renewable Energy Laboratory's (NREL's) dGen model (discussed below). However, no commercially available tools to determine customer adoption (element 3). One challenge with forecasting DER adoption rates (element 3) is that they are impacted by policies, programs, and incentives, but policies, programs, and incentives rely on projections in distribution system planning.

4.1.1 Tools and Approaches for Developing Forecasts

4.1.1.1 *Forecasting Load*

Traditional distribution system analysis tools—such as CYME, Synergi and MilSoft—support the development of feeder-level load projections. These have traditionally been developed in a relatively straight-forward way by taking the current system loads and applying a load-growth factor to forecast ahead. Some distribution system analysis tools have add-ons that produce different scenario forecasts and allow the user to vary growth rates in different regions. For example, CYME's Automated Network Forecast Tool (http://www.cyme.com/software/cymdistforecaster/) and Advanced Project Manager (http://www.cyme.com/software/advprojmgr/) add-ons offer these capabilities.

NREL's dsgrid (https://www.nrel.gov/analysis/dsgrid.html) is a demand-side grid model that uses a bottom-up methodology to enable detailed analyses of current patterns and future projections of end-use loads.

LoadSEER is a spatial load-forecasting tool for T&D systems that produces a time-series analysis for future-load growth based on forecast scenarios. LoadSEER integrates geospatial and advanced metering infrastructure (AMI) data, along with historical and forecasted weather information to develop regularly updated multi-scenario load forecasts.[xv] Some of the most advanced utilities in California, Hawaii, and New York are using LoadSEER to develop granular load projections.

4.1.1.2 *Forecasting DER*

To develop different DER growth scenarios, utilities use market analysis reports, potential studies, procurement requirements, and internal company analyses. One challenge with forecasting DER adoption rates is that they are impacted by policies, programs, and incentives. However, policies, programs, and incentives rely on projections in distribution system planning. Tracking and forecasting DER generation and new DER deployment requires an array of new approaches and tools. New commercial tools are being developed for projecting DERs, including some that utilize machine-learning methods.

4.1.1.3 *WattPlan Grid*

WattPlan® Grid (https://www.cleanpower.com/products/wattplan/grid/) is a cloud-based DER forecasting tool that Clean Power Research and SMUD (Sacramento Municipal Utility District) are developing. It is based on customer adoption modeling, and it uses machine learning and advanced data analytics.

4.1.1.4 *dGen Model*

NREL's dGen model (https://www.nrel.gov/analysis/dgen/) is a geospatially rich, bottom-up, market adoption model that simulates the technical and economic potential adoption of DERs for residential, commercial, and industrial entities in the United States through 2050. dGen helps determine technical and economic potential forecasts. It represents customer decision-making through an agent-based framework and the use of spatially resolved data sets. dGen can help utilities understand where to expect future deployment of PV fleets; however, it would not provide the necessary information to develop the short- or medium-term forecasts necessary for distribution system planning.

4.1.1.5 *Utility-Developed Method: Bass-Diffusion Models*

Some advanced utilities in California and elsewhere are working with consultants to develop their own analysis tools that utilize Bass-Diffusion models to project DER adoption.

Many industries use Bass-Diffusion models, which are models based on a sociological theory that adoption of a new technology is a function of early adopters influencing later adopters. The Bass-Diffusion Model was developed by Frank Bass and consists of a differential equation that describes how new products get adopted in a population. Some electric utilities are developing models based on generalized Bass-Diffusion theory to conduct DER forecasting. Bass-diffusion modeling is derived from Bass-Diffusion theory and basic assumptions about market size and the expected behavior of innovators and imitators.[xvi]

While Bass-Diffusion technology adoption modeling is useful for generating macro-level results, it does not account for unique customer variables, and it is unable to account for the unique impact of many individual customer-level predictive variables—like proximity to other adopters, home size, customer engagement data, etc. Bass-Diffusion modeling requires knowledge of the relationship between the market potential and the payback period that must be determined through surveys, which can be difficult to determine and keep current. A multitude of customer-level data is required for producing very granular results.

Southern California Edison and Pacific Gas and Electric in California use a generalized Bass-Diffusion modeling framework for PV projections. It is a regression-based standard technology adoption model that attempts to capture future customers' decision-making about adopting PV based on PV cost effectiveness and adoption constraints. Both utilities then adjust the results based on expected policy changes that are not reflected in the historical-based regression, such as building codes require that all new houses constructed starting in 2020 be "zero net energy."[xvii]

Utilities conduct these analyses individually with tools developed by consultants. For instance, Pacific Gas and Electric worked with Navigant to develop a modeling tool utilizing Analytica software.[xviii]

Once the PV adoption estimates are developed using Bass-Diffusion modeling and adjustments for specific policies, the California utilities then project actual generation from behind-the-meter solar by using results from NREL's PV Watts model, which forecasts hourly generation by climate zone using typical system configurations for the residential and non-residential sectors.

4.1.2 Advanced Functionality Needed

Commercial tools are available that project customer loads in a granular way, but there is a lack of commercial tools that forecast DER adoption and net load in a granular way. WattPlan Grid, currently under development, is working on advanced DER projecting functionality. However, there are no traditional distribution system analysis tools that currently have the capability to endogenously predict DER growth based on customer adoption modeling.

Existing tools are good at projecting solar energy production but are not good at projecting wind production at a distributed scale. More specific projections on battery storage deployment and operations are needed for planning purposes.

Table 1. Multiple-Scenario Forecast Tools and Methods

Capability	Tools and Methods*	Advanced Functionality Needs
Load Forecasts: Provide a granular estimate of future loads on a circuit.	• LoadSEER integrates geospatial and AMI data along with historical and forecasted weather information to develop regularly updated multi-scenario load forecasts. • CYME, Synergi, and MilSoft have add-on modules for developing multiple-scenario forecasts. • NREL's dsgrid creates detailed electricity load data sets.	• Continued refinement of granular forecast methodology.
DER Adoption Forecasts: Project the potential of future DER adoption on the distribution system.	• dGen forecasts technical and economic potential but does not project customer adoption in the short term.	• Commercial/mature tools that project customer adoption. • WattPlan Grid, a tool currently in development, will use machine learning and advanced analysis for project customer adoption.
DER Energy Production Forecasts: Given projected adoption rates, energy production forecasts indicate the energy generation by time and location.	• dGen from NREL • Solargis • SolarAnywhere • Project Sunroof • PV Watts	• Existing tools are good at projecting solar energy production, but they are not good at projecting wind production at distributed scale.

Capability	Tools and Methods*	Advanced Functionality Needs
		• More specific battery storage information is needed for modeling.

***Not an exhaustive list**

4.2 Time-Series Power Flow Analysis

Power flow analysis is the core of power system analysis. It is used to calculate and assess voltages, currents, losses, and real and reactive power flows in distribution circuits and feeders under different, current, and potential future conditions. Power flow analysis can tell planning engineers whether the system voltages will remain within specified American National Standards Institute limits or whether equipment is overloaded. This is a critical factor in understanding the impacts of DERs, and it is fundamental for hosting capacity and interconnection analysis studies.

Power flow analysis plays a key role in traditional distribution system operation and planning, but—like other areas—it is evolving to consider changing operating conditions as more DERs are connected to the distribution system. Historically, distribution system planners performed detailed power flow analysis using static snapshot simulations at the expected yearly peak-load condition to determine if the system could safely handle the peak load. Now, with DERs creating a more variable supply and demand picture, distribution system planners must look beyond just the system peak, and utilities have started to move from snapshot simulations to time-series simulations using TSPFA. A time-series simulation is composed of multiple steady-state power flow calculations with user-defined time step sizes between each calculation. These are then used to assess load profiles, effects of irradiance variations or wind fluctuations on power system controls, and the sequence and performance of automatic switching, voltage control, and protection system operations.[xix] TSPFA is increasingly important with DERs because it allows for the necessary detailed simulations required to understand how DERs impact the grid, both positively and negatively.

4.2.1 Tools

TSPFA is provided in most commercial distribution system analysis tools as an add-on; open-source distribution system analysis tools, such as GridLAB-D and OpenDSS, also include TSPFA. However, adoption of TSPFA by utilities is still quite low due to its nascent form and relative complexity, as well as the lack of suitable data for time-step functions.

4.2.2 Advanced Functionality Needed

As described above, many utilities do not have the granular data inputs necessary for TSPFA. In addition, traditional TSPFA simulation that provides the necessary granularity is computationally challenging and can take anywhere from 10 to 120 hours on a single computer.[xx] Even with fast iterative solvers, solving the unbalanced three-phase power flow equations of the distribution system millions of times can take significant computational efforts.[xxi]

Speeding up TSPFA through a variety of proposed approaches is an important and emerging area of study that will support a more detailed distribution system analysis. However, this requires caution because there are important tradeoffs that must be considered. For example, faster computation times can result in reduced details on power-flow impacts. TSPFA approaches that are faster and less computationally intensive represent a gap.

TSPFA is generally unable to perform dynamic or transient analyses that are common in the bulk power modeling arena and necessary for considering frequency and inertia issues. Some of the tools that offer TSPFA do so in a relatively limited capacity. Dynamic and transient analyses are important for issues such as flicker, perhaps due to cloud-induced variability in solar PV systems or wind gusts, which can potentially be problematic for utilities and their customers if not mitigated. With greater levels of DER deployment, there is a higher level of interest in accurately modeling dynamic and transient impacts, but this capability does not currently exist in commercial tools.

Table 2. Time Series Power Flow Analysis Tools and Methods

Capability	Tools and Methods*	Advanced Functionality Needs
Calculate multiple steady-state power flows conducted at a user-defined time step in order to understand DERs' impacts to the grid.	Available in most commercial distribution system analysis tools and lab/research tools.	• Reliable streamlined methods that reduce computation times. • Dynamic and transient analysis capabilities for assessing frequency and inertia.

*Not an exhaustive list

4.3 Hosting Capacity and Interconnection Studies

Hosting capacity analysis and interconnection studies are increasingly important as part of distribution planning and both require a similar approach. The difference though is that hosting capacity analysis evaluates the amount of DERs that can be connected to a feeder or circuit without affecting feeder power quality or reliability; whereas, an interconnection study covers the same technical issues, but for a single DER project. Hosting capacity studies require both distribution feeder modeling and analysis.

Utilities can use hosting capacity to streamline the interconnection process by using a predetermined hosting capacity level, together with the current adoption levels and anticipated DER growth. It can also provide a middle ground between the less accurate fast-track screens and the more involved interconnection study analysis that can be expensive and time consuming. Hosting capacity can also be used for long-term distribution planning to help utilities identify the infrastructure needed to accommodate anticipated DER growth and target DERs in areas with higher hosting capacities. Hosting capacity analysis is also valuable for DER developers because it allows them to identify locations where it might be easier to add new DERs or areas that would likely require infrastructure upgrades, allowing them to evaluate project locations upfront rather than having to guess or wait for a utility analysis.

A hosting capacity analysis typically consists of a set of automated distribution system analyses. This analysis is then repeated for increasing amounts of projected interconnected DERs, until one or more of the analysis results exceeds a predetermined threshold. These thresholds or evaluation criteria for the hosting capacity analysis focus on four main areas: (1) voltage (reliability and service quality), (2) power quality (harmonics), (3) protection (reliability), and (4) thermal limits (loading and reliability). Challenges utilities face related to hosting capacity analysis include coordinating data between systems and the large amount of information required, including feeder models, loads, and DER characteristics. Expertise needed to conduct hosting capacity analysis can also be a gap.

4.3.1 Tools and Approaches

Distribution system analysis tools are generally capable of conducting the analyses required for hosting capacity studies, but they frequently require external custom scripts in order to automate the often-considerable amount of analysis undertaken in such studies. Some large and relatively sophisticated utilities have spent a significant amount of money to automate hosting capacity and interconnection studies. However, some tool developers are working to automate hosting capacity calculations within their tools. Automating hosting capacity or project impact studies would allow for automated interconnection studies and reduce the overall time utilities spend to process DER applications. The present approach for DER impact study analysis is somewhat of a manual approach, and once an interconnection application “fails” technical screening criteria, the application goes through the detailed study process.

There are four different hosting capacity methodologies in use: (1) streamlined, (2) iterative, (3) stochastic, and (4) hybrid approaches. In the streamlined approach, a baseline feeder performance is established and then the hosting capacity of each electrical node in the feeder model is examined with increasing DER adoption levels. With the hosting capacity determined for each node of the feeder, a hosting capacity range is determined for each feeder section and for the whole feeder. The accuracy of this method depends on system complexity and can yield sub-optimal results for complex systems and large amounts of DERs.

The second method is the detailed iterative methodology. Large California investor-owned utilities use this approach, which is based on a stochastic analysis. In this method, the analyst performs multiple power-flow simulations with varying levels of DERs connected to each node (parallels typical interconnection studies). The utilities perform hosting capacity calculations over a 12-month period using 1 day per month of both typical high-load and low-load conditions (12×24×2=576 hours). CYME has an add-on module that uses the iterative method—the CYME Integration Capacity Analysis module (http://www.cyme.com/software/cymeica/). Synergi is also able to conduct hosting capacity analysis using the iterative method.

The third method is a stochastic approach. The DER deployment on a feeder is increased throughout the feeder using randomly chosen DER sizes and locations to simulate thousands of different scenarios. Pepco and ComEd use this approach.

Finally, the hybrid approach (also referred to as the EPRI DRIVE method) applies statistical distributions to equations to account for dispersion of DERs on a given circuit and for breadth of the distribution network. It can be described as a hybrid stochastic-streamlined approach, and it is a proprietary method with implementations for many distribution analysis tools. Xcel, National Grid (in New York and Massachusetts), TVA, Southern Company, and several other utilities use this approach.

EPRI DRIVE can interface to the commonly used distribution system analysis tools, OpenDSS, CYME, Synergi, and Milsoft Windmil, and is being implemented in PowerFactory. The implementation of the EPRI DRIVE approach has been customized based on specific database structures and data sets in various tools.

4.3.2 Advanced Functionality Needed

Hosting capacity for PV is well understood, but wind and multi-resource hosting capacity are not as well understood. Hosting capacity analysis is a screening tool that can be used to indicate the amount of PV that a feeder can handle before problems arise. An interconnection study can tell a utility more about how the system will behave with a specific project. Larger questions that have yet to be addressed in existing tools are: what is the solution to that interconnection study issue; or, what can and should be done to address the exceedance of a circuit's hosting capacity? There is a need to go beyond the hosting capacity cap to determine the engineering solutions that will meet system needs and policy objectives.

There is a suite of potential solutions for addressing a hosting capacity exceedance. Solutions can take the form of controls, capacitors, battery storage systems, reconfiguring circuits, or demand-side solutions. Detailed engineering studies can be performed to look at each of these solutions. From a tools perspective, all the traditional distribution system analysis tools (CYME, Synergi, Milsoft), as well as the research tools (GridLAB-D and OpenDSS), can be used to manually perform analysis and explore different solutions. But the challenge is that these solutions are manual. One gap that exists is a tool **that can review and assess the potential solutions to interconnection studies or hosting capacity analysis in an automated way, as well as recommend the best resource or combination of resources to meet system needs.**

Existing optimization tools such as HOMER, DER-CAM, and ReOpt (discussed in Section 5.2.1) have some existing capabilities to identify DERs that meet system needs, but a detailed engineering analysis is needed on top of those tools, and analyses need to happen in an automated way. This is something that is not necessarily needed today but will be needed in 5–10 years as utilities struggle to understand how to accommodate increasingly higher levels of DERs. National-level research activities can support the development of this type of front-runner tool.

In existing hosting capacity tools, gaps still exist around loading and reliability, as well as workflow/automation of hosting capacity analyses. The data needed for modeling feeders, loads, and DERs are not always available; this represents another gap. Another gap is hosting capacity analysis that takes into account protection coordination issues. Finally, system data and model validation are gaps that limit many utilities' ability to conduct hosting capacity analysis. As a first step, many utilities find they need to improve or clean up existing data sets.

Table 3. Hosting Capacity Tools and Methods

Capability	Tools and Methods*	Advanced Functionality Needs
Determine the amount of DER that can be accommodated on a feeder without adverse impacts; identify locations on a feeder (or capacity of a feeder) for new DER.	• EPRI DRIVE – a hybrid stochastic-streamlined approach available as an add-on to existing distribution system analysis tools. • CYME and Synergi have add-on modules that use the iterative approach. • GridLab-D and OpenDSS can be used to conduct hosting capacity analysis studies. • EDD/NISC/DEW software.	• Automatic determination of optimum resource combinations to mitigate hosting capacity exceedances. • Analysis associated with protection coordination. • Real-time updating and semi-automated approach to evaluating interconnection requests.

*Not an exhaustive list

4.4 Locational Value Analysis

Locational value analysis helps utility planners understand the benefits and costs of DERs at a specific location on the distribution system. There are two parts to locational value assessments: (1) understanding the physical implications of DERs on the grid and (2) understanding the value. Most commercial and research tools for distribution system analysis can be used to understand the physical impacts of DERs on the grid, but assessing this value is complex, and it is an emerging area of study and application because the value does not depend solely on where the technology is located on the system. A technology's value depends on several variables and can vary depending on the time of the day and/or year.

While it is complex, locational value analysis is valuable because it can:[xxii]

1. Support the development of a public tool and heat map to indicate high-value locations for certain types of DERs.
2. Assist utilities in prioritizing distribution deferral opportunities, also referred to as non-wires alternatives.
3. Allow a comparison of various projects.
4. Inform compensation and incentives strategies.

Specific distribution system investments that can be avoided often drive locational value. DERs may avoid the need for energy and associated fuel, operations and maintenance costs, additional generating capacity, deferred distribution capacity upgrades, and emissions.[xxiii] DERs may cause additional costs if equipment is not capable of bi-directional power flow, requiring upgrades to different types of equipment on the distribution system. DERs may lessen the life of load tap changers and may adversely impact protection schemes.

Non-wires alternatives (NWAs) in the context of distribution system planning are investments in energy efficiency, demand response, distributed generation, and storage that provide particular services at given locations as a way to defer, mitigate, or eliminate the need for traditional distribution infrastructure investments.[xxiv]

In some cases, NWA suitability criteria are established and used to determine which planned system upgrades may be good candidates for NWAs. In some cases, NWA opportunity information is available via public websites. Utilities can use a solicitation process to request and select specific NWA projects that meet system needs.

To begin an NWA analysis, it is first necessary to use traditional tools and methods to identify constraints or areas that might need upgrades or investments. Utilities then evaluate each case to determine which projects could potentially be avoided by using non-traditional or a non-wires alternative.

Planning for NWAs and developing suitability criteria requires establishing the DER characteristics in terms of availability and performance. Therefore, utilities need tools that can characterize the performance and cost of DER alternatives.

NWAs – Example State Approaches

New York and Rhode Island

At the behest of the respective state utility regulator, New York and Rhode Island utilities developed suitability criteria to identify candidate NWA projects. Suitability criteria include project type (such load relief and reliability), timeline and cost.[xxv]

- **Project Type** – Identifies the project types that are better suited to NWA. New York is currently pursuing the load relief and reliability project types. For New York, other NWA project categories (such as power-quality, resilience, and new business) have been determined to have minimal suitability at this time. Suitability of these types of projects for NWAs will be re-reviewed as state policy or technological changes occur.
- **Timeline** – Defines the time needed to complete the procurement process, including developing and issuing requests for proposals, vendor response, technical review of proposals, contracting, and implementation. In New York, large project timelines are 36–60 months and small project timelines are 18–24 months.
- **Cost Suitability** – Determines costs floors for which a traditional investment would be evaluated for NWA options. Above a certain cost threshold, it is assumed that project costs are enough to overcome transaction and opportunity costs. In New York, cost suitability for large projects is greater than $1 million and for small projects less than or equal to $300,000.

California

The California Public Utilities Commission (CPUC) requires the investor-owned utilities to file a grid needs assessment and distribution deferral opportunity report each year. The objective of the report is to identify specific deficiencies of the distribution system (by circuit), identify the cause of the deficiency, and serve as the basis for an annual project list of necessary distribution system upgrades.[xxvi] The distribution deferral opportunity report addresses planned investments and candidate deferral opportunities separately.[xxvii] The CPUC directs utilities to identify NWA opportunities using proposed “technical and timing” screening criteria. The IOUs must determine that a candidate investment could technically be addressed using DERs and that sufficient time exists to issue the requests for proposals, select bidders, and install DERs in in a timely fashion.[xxviii]

Additional functionality needed for NWA includes planning tools that can automatically identify a set of appropriate NWA for a particular application given system needs and constraints. Thus far, utilities are primarily using NWAs for projects associated with load growth and reliability. Advanced NWA functionality in planning tools would evaluate the ability of different configurations of NWA to provide the following:

- Load relief
- Reliability
- Power quality
- Voltage optimization
- Resilience
- New business and service upgrades

Tools for assessing the physical impact of DERs on the grid include both commercial and research power-flow simulation tools. Tools for assessing value include marginal cost of service studies, which explore how costs are projected to change over time in response to changes in customer usage and generation[xxix], and detailed power-flow models that can illustrate the difference between infrastructure needs, and thus potentially avoidable costs, with and without DERs.[4]

[4] Information on challenges and opportunities associated with marginal cost of service studies can be found in the report: *Electric Cost Allocation for a New Era – A Manual* by the Regulatory Assistance Project: https://www.raponline.org/blog/cost-allocation-new-approaches-for-a-new-era/

Primary inputs for locational value calculations rely on results from the distribution planning process, including identifying specific projects that can be deferred (costs and install/commitment year), as well as load forecasting and DER development. Therefore, a robust and comprehensive distribution planning process that includes a needs assessment and investment planning is important for locational value determinations.

4.4.1 Tools and Approaches for Conducting Locational Value Assessments

No single tool exists for calculating locational value. Utilities use different tools to assess different components of locational value, and some are developing their own approach. The next two sections describe some utility-developed approaches and research tools, respectively, for characterizing the locational value of DERs.

4.4.1.1 *Utility-Developed Approaches*

4.4.1.1.1 Marginal Cost of Services Studies (New York)

In New York, marginal cost of services studies (MCSS) form the basis of a new value stack tariff designed to compensate DERs for the value they provide to the grid. Marginal costs are the unit investment in dollars per kilowatt hour ($/kWh) needed to accommodate incremental load growth. Traditional utility MCSS calculate marginal costs on a system-wide average basis and do not provide data at the distribution feeder level. To perform the MCSS necessary for the new tariff, ConEdison hired Brattle Group and EnerNex LLC to develop a tool that evaluates the marginal costs associated with DERs at a specific location on the distribution feeder.

Current marginal cost calculations depend on information available from actual or planned projects, specifically investment costs, and the timing and location of investments. Brattle found that the availability of this information was relatively limited.[xxx]

An identified gap is the quality and quantity of data for various projects used to estimate the costs and frequency of upgrades in the future. Data collected over multiple years is needed to observe year by-year trends in system investment costs, rather than assuming historical costs will carry forward. Because investments are lumpy, it is difficult to parse apart the costs of serving the next increment of load growth with reliability improvements and other grid services. There are other significant challenges of applying MCSS results to compensation strategies for DERs. These include the life of DERs, typically 20 years, as compared to the planning horizon of many MCSS (typically 10 years), and the fact that reliability contributions from DERs are not accounted for in the MCSS.[xxxi]

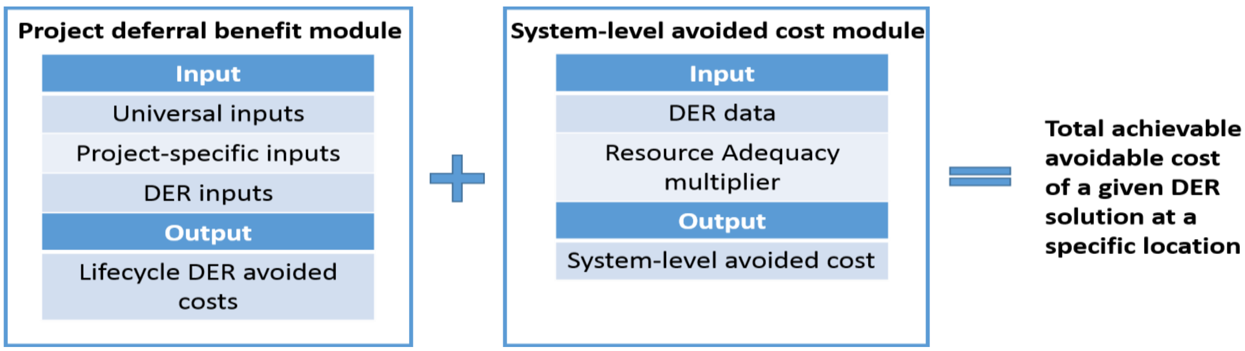
The tools used to conduct MCSS are simple spreadsheets with cost and present value calculations. In this case, it is not the tool that needs support, but rather the data, analysis assumptions, and application of the results that could be addressed with a recommended and standardized best practice approach for carrying out MCSS developed through a long, concerted, and collaborative effort.

4.4.1.1.2 Locational Net Benefits Assessment Tool (California)

In California, the three largest investor-owned utilities jointly engaged the consulting firm Energy and Environmental Economics, Inc (E3) to develop a technology-agnostic Excel tool for estimating location-specific avoided costs of DERs for demonstration projects. The Locational Net Benefits Analysis (LNBA) tool takes into account the hourly costs and benefits over the life of the DERs (up to 30 years) using California's standardized avoided cost calculator, called the DER Avoided Cost Calculator, or DERAC, a method/calculator developed by E3.

As shown in Figure 4, the California LNBA tool has two major parts: (1) a project deferral benefit module, which calculates the values of deferring a specific capital project; and (2) a system-level avoided cost module, which estimates the system-level avoided costs given a user-defined DER solution. Summing the quantitative results of the two modules provides an estimate of the total achievable avoidable cost for a given DER solution at a specific location.

Figure 4. Components of California's LNBA Tool



Inputs for the project deferral benefit module of the tool (shown in Table 4) include DER location, DER type, DER useful life, and DER install year. The project deferral benefit module also relies on the distribution planning process, including identifying specific projects that can be deferred (costs and install/commitment year), as well as load forecasting and DER development. In the methodology, DER growth scenarios must be developed along with load forecasts based on existing DER tariffs and programs.

Table 4. DERAC Deferral Benefit Module Inputs (E3 2017)

Universal inputs	Discount rate
	Revenue Requirement Multiplier
	Equipment inflation rate
	O&M inflation rate
Project-specific inputs	Book life O&M factor Project identifiers
	Equipment type
	Project cost
	Project install/commitment year
	Project flow factors
	Loss factors
	Load profile/need profile
	Overloading threshold magnitude and hours
DER inputs	DER type and location
	DER useful life
	DER install year
	Defer T&D to this year
	Hourly DER profile
	Dependability in local area

DERAC—the E3-developed tool that utilities used to calculate system-level avoided costs—is an Excel-based spreadsheet model for use in demand-side cost-effectiveness proceedings at the CPUC.[5] The tool can produce an hourly set of values over a 30-year time horizon that represent the costs the utility would avoid because of power supplied from DERs. The utility uses these avoided costs and the benefits to determine the cost effectiveness of DERs. The components of the electricity avoided costs that DERAC calculates include avoided cost of generation capacity and energy, ancillary services (AS), T&D capacity, greenhouse gas, and renewable portfolio standards (RPS) (listed in Table 5). Each component is calculated for every hour of the year.

Table 5. Components of Electricity Avoided Costs Calculated by DERAC [xxxii]

Component	Description
Generation Energy	Estimate of hourly wholesale value of energy
Generation Capacity	The costs of building new generation capacity to meet system peak loads
Ancillary Services	The marginal costs of providing system operations and reserves for electricity grid reliability
T&D Capacity	The costs of expanding transmission and distribution capacity to meet peak loads
Environment	The cost of carbon dioxide emissions associated with the marginal generating resource
Avoided RPS	The reduced purchases of renewable generation at above-market prices required to meet an RPS standard due to a reduction in retail loads

4.4.2 Research Tools that Support Locational Value Assessments

What follows are example tools developed by national laboratories or research organizations that support locational value assessments.

4.4.2.1 *GridLAB-D*

GridLAB-D is a physics-aware simulation tool used to project the physical state of a system for a given scenario or set of initial conditions. Pacific Northwest National Laboratory (PNNL) developed GridLAB-D, a distribution system simulation tool with detailed models from the substation to individual households. GridLAB-D can be used to not only determine system impacts of DERs but also to assess grid impacts and the cost and rate impacts of distributed generation and flexible loads.[xxxiii]

4.4.2.2 *OpenDSS*

OpenDSS is a physics-aware simulation tool used to project the physical state of a system for a given scenario or set of initial conditions. OpenDSS (https://www.epri.com/#/pages/sa/opendss?lang=en), developed by EPRI, is a distribution system simulator designed to support integration of DERs and grid modernization. OpenDSS models traditional and advanced distribution technologies, resources, assets, and controls, and it was the first platform to include detailed energy storage and advanced inverter data. OpenDSS is open source.

[5] DERAC can be downloaded here: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=12509

4.4.2.3 *Financial Impacts of Distributed Energy Resources (FINDER)*

Financial Impacts of DERs (FINDER) is an economic study tool used to project the value or cost of a system or resource. FINDER (https://emp.lbl.gov/projects/finder-model), developed by Lawrence Berkeley National Laboratory (LBNL), calculates annual utility costs and revenues associated with DERs based on utility-specific physical, financial, economic, and ratemaking information, along with DER production or savings information and costs. Key outputs include achieved return on equity and earnings, average retail rates, and customer bills. The utilities, policy makers, customer groups, and other stakeholders can use the results from FINDER outputs when assessing the impacts and implications of policy proposals and decisions.

4.4.2.4 *Distributed Energy Resources Customer Adoption Model (DER-CAM)*

Distributed Energy Resources Customer Adoption Model (DER-CAM) is a planning tool. DER-CAM (https://building-microgrid.lbl.gov/projects/der-cam), developed by LBNL, is a decision support tool for decentralized energy systems. The outputs of the tool include optimal DER and storage adoption combination, and an hourly operating schedule, as well as the resulting costs, fuel consumption, and CO_2 emissions. DER-CAM+ builds on the original DER-CAM tool and includes electrical power-flow and thermal-flow equations and constraints in the microgrid, and it considers revenues considerations from various ancillary services markets, including spinning and non-spinning reserve and up and down frequency regulation.[xxxiv]

4.4.2.5 *Integrated Energy System Model (IESM)*

Integrated Energy System Model (IESM) is a physics-aware simulation tool used to project the physical state of a system for a given scenario or set of initial conditions. IESM, developed by NREL, combines multiple simulation tools—including the PNNL's developed power-flow simulator, GridLAB-D—to analyze the interactions between multiple technologies within various market and control structures, to identify both financial and physical impacts on consumers and utilities. IESM can be used to understand and test the impact of new retail market structures and technologies, such as DERs, demand response equipment, and energy management systems on cost and the system's ability to provide reliable electricity to all customers.[xxxv]

4.4.2.6 *System Advisor Model (SAM)*

System Advisor Model (SAM) is an economic study tool used to project the value or cost of a system or resource SAM (https://sam.nrel.gov/), developed by NREL, calculates performance and financial metrics of renewable energy systems. SAM simulates the performance of PV, concentrating solar power, solar water heating, wind, geothermal, and biomass. The financial model can represent financial structures for projects that either buy or sell electricity at retail rates (residential and commercial) or sell electricity at a price determined in a power purchase agreement. Project developers, policymakers, equipment manufacturers, and researchers may use SAM results to evaluate financial, technology, and incentive options for renewable energy projects.

4.4.3 Advanced Functionality Needed

Due to its complexity and the variable nature of inputs, locational value analysis is a new, developing area, and many gaps exist. To fully evaluate the locational value, utilities need new analysis capabilities to assess the physical impacts of DER, as well as the value they can provide.

Advanced functionality needed for assessing <u>physical impacts</u> of DERs includes the following:

- Understand the physical impacts of multiple smart inverters and/or energy storage systems operating together on a circuit under different loading and operations conditions. Existing research and commercial tools can to do this to a limited degree.
- Quantify the impacts of different types of DERs to ancillary services.
- Address the impacts of DER on power quality.
- Understand and quantify the reliability and resilience impacts of different types of DERs to the distribution and transmission systems. Reliability and resilience impacts have not been quantified.
- Characterize the physical impacts of different types of DERs on the transmission system. The national laboratories are developing new co-simulation tools to help with this and organizations like the Western Electricity Coordination Council are also advancing this type of analysis.

Advanced functionality needed for assessing DER <u>value</u> to the distribution grid includes the following:

- Developing a tool that automatically calculates value (in terms of avoided or incurred costs) from physical engineering impact assessments of different DER configurations.
- Assessing risk hedging impacts of DERs and the associated value. These risk hedging impacts extend beyond immediate economic value to things like reliability and resilience.

In many states, like California, the cost-benefit analysis is completed using spreadsheet calculators tied to avoided cost and marginal cost studies. Results are only as detailed as inputs. Some value elements are difficult to quantify, and proxies or approximations can be used.

In addition, standard methods for conducting marginal cost of service studies and applying those results to planning and DER compensation strategies are needed. Without standardized methods, each utility may perform marginal cost studies differently and include different components. Standardization, or at a minimum identification of a suite of best practices, would support utilities and regulators as locational value characterizations become increasingly important.

Table 6. Tools and Methods for Assessing Locational Value in Distribution System Planning

Capability	Tools and Methods*	Advanced Functionality Needs
Calculate specific locational value of a DER project.	• Utilities are developing spreadsheet calculators to track potentially avoidable projects and costs (e.g., DERAC developed by E3 for the California utilities). • In California, LNBA Tool (E3) was developed as an addition to DERAC to identify locational benefits of DERs. • Other tools that support the determination of locational value: Kevala Network Assessor, HOMER Grid, GridLAB-D; OpenDSS; FINDER; DER-CAM; IESM; and SAM.	• Tools that support the calculation of value (in terms of avoided or incurred costs) from physical impact assessments. • Tool that automatically select a set of appropriate NWA given system needs and constraints. • Characterization of impact of DERs on resilience, reliability, power quality, and the transmission system. • Characterization of the impacts of multiple smart inverters and/or storage systems operating on a circuit. • Characterization of resilience and risk hedging impacts of DERs.

*Not an exhaustive list

4.5 Enterprise-Level Analysis and Planning Platforms

A few commercial tools have been or are being developed that can be called enterprise-level analysis and planning platforms. These tools collect and aggregate data streams and conduct different types of analyses in support of distribution system planning and grid modernization. Analyses include scenario analysis, hosting capacity and interconnection analyses, and assessment of NWAs. These tools also address managing overall utility workflow and, in some cases, support customer-interfaces, such as billing and customer-facing websites.

4.5.1 Tools

GridUnity™, GridOS®, and Prosumer Grid™ (in development) are three enterprise-level platforms that aggregate multiple data streams for conducting different analyses for enhanced distribution system planning with DERs. GridUnity (https://gridunity.com/) is designed as platform-as-a-service and combines predictive analytics, machine learning, and cloud computing with a business logic engine to address challenges in distribution systems. GridUnity uses lab tools such as GridLAB-D on the back end to perform power flow analysis. It can calculate hosting capacity and analyze mitigation strategies.[xxxvi] GridUnity connects physical information with financial information to support utility business decision-making.[xxxvii]

Opus One Solutions' GridOS Integrated Distribution Planning product[xxxviii] is intended to support utilities' distribution system planning process. It is a cloud-based, scalable, automated solution for utilities to use in distribution system planning that combines traditional power-system engineering, advanced analytics, and software technologies.

ProsumerGrid (https://prosumergrid.com/) is in development and is being designed as a set of software solutions that enable simulation, planning, and decentralized coordination of DERS.

4.5.2 Gaps

A key gap associated with these enterprise platform systems is related to data availability and consistency. Utilities have developed multiple planning, operations, control, and customer systems piecemeal through various vendors over a period of years. Many utility systems have proprietary data and data management systems, so a special program in the proprietary code language must be written to unlock and share data between systems. Data standardization is needed between asset management, demographics, and power flow. As one enterprise tool developer put it, “Bringing different data sets together is a huge challenge. Without standard data formats we are stuck.”[xxxix]

Table 7. Enterprise Analysis and Planning Platforms for Distribution System Planning

Capability	Tools and Methods*	Advanced Functionality Needs
Software platforms that aggregate data streams and analyses in support of interconnection analyses, distribution system planning, and utility workflow.	• GridUnity • GridOS • Prosumer Grid (in development)	Data availability, consistent data standards, and formats.

*Not an exhaustive list

4.6 Coordinating T&D Planning

As more DERs are connected to the distribution system, it is becoming important to evaluate the impact that large number of DERs might have on the transmission system. At high enough DER adoption levels, reverse power flow from the distribution to transmission system can occur. Operating conditions on the transmission system also have the potential to impact DER operation in terms of ride-through capability and frequency and voltage impacts. There is also the potential for DERs to provide non-transmission alternatives or conversely, transmission upgrades may be required as a result of DER adoption. Separate data sets, simulation software, and models support planning for T&D. Traditionally, only certain limited data (primarily load) has been shared between the distribution and transmission systems. However, to understand and examine the interactions between the systems as a result of increased DER adoption and their variable generation characteristics, will require an integrated view of transmission, distribution, and DERs. This is resulting in a transition from a strictly transmission-to-distribution hierarchy to one of a more of a co-equal paradigm. This change represents a significant modeling challenge due to the traditionally separate distribution and transmission modeling tools.

4.6.1 Emerging Tools

Researchers have developed steady-state global power flow models that solve the distribution and transmission system together, and these global models are just starting to capture the important dynamic/transient effects. One example is the California Energy Commission’s “Regional Transmission and Distribution Network Impacts Assessment for Wholesale PV Generation.”[xl] However, the computational burden of modeling the T&D systems together is immense. As an alternative, co-simulation platforms are emerging that link existing T&D dynamic simulators. The DOE is funding a multi-laboratory effort to develop a co-simulation tool, called the Hierarchical Engine for Large-scale Infrastructure Co-simulation (HELICS). It is estimated that detailed co-simulation tools, such as HELICS, are roughly five years from reaching widespread commercial availability.

4.6.2 Advanced Functionality Needed

Advanced functionality needed includes improving the usability and scalability of T&D co-simulation tools, commercial co-simulation platforms or models that can simultaneously model or simulate the distribution and transmission system.

Table 8. T&D System Co-simulation Tools and Methods for Distribution System Planning

Capability	Tools and Methods*	Advanced Functionality Needs
Co-simulate T&D system power flows.	• HELICS and Framework for Network Co-simulation (FNCS) for co-simulating distribution and transmission. • CyDER for DERs in smart grids.	Improved usability and scalability of co-optimization tools.

*Not an exhaustive list

4.7 Advanced Optimizations

The increasing deployment of DERs increases the potential benefit from robust tools that can help assess the optimal siting and sizing of DERs to achieve planning and operations objectives. Optimizing the DER type, location, and sizing requires utilities to determine the types of DERs, their location, and sizes that will provide the most benefits to the grid based on specific policy goals and/or system needs. Non-optimal installation and schedule of DERs may result in the increase of system losses and corresponding costs. Numerous strategies and methodologies have been proposed in recent years to address optimal DER integration and planning; however, widespread implementation of the methods has not taken place.[xli]

Advanced technologies, including demand response, electric transportation, electric heating, and energy storage have posed uncertainties on operational optimization of DERs. A stochastic approach can be used for the assessment of the operational uncertainties;[xlii] however, stochastic approaches are time consuming and data intensive.

4.7.1 Tools

None of the most common distribution system analysis tools evaluated for this paper are able to perform utility-wide advanced optimizations, although customized scripts can be added into the tools that support DER planning and single variable optimization.[xliii] The standard distribution system analysis tools used to evaluate a limited number of discrete DER options may provide a robust and fast alternative to exhaustive optimizations given the challenges described.

HOMER is a commercial tool that can optimize DERs within a village, island, campus, or military base. NREL’s ReOpt Model and LBNL’s DER-CAM (Customer Adoption Model) both support the evaluation of optimal DERs and storage adoption combinations at the building or microgrid level, but not the full distribution system. These tools use a balance of energy approach rather than full engineering power flow analysis. Without power flow analysis, these tools cannot provide insights into voltage levels, power factors and line losses limiting understanding of reliability and efficiency impacts of different scenarios.

True optimization of DERs would include not only optimizing based on the distribution system only, but also based on the needs and behavior of the transmission system as well. Integrated models that include both T&D systems are in development at laboratories and research organizations, but are not ready for commercial application.

A multi-lab GMLC effort[6] is focused on developing a DER siting and optimization tool for California that identifies DER adoption patterns, potential microgrid sites, and demand-side resources, and also evaluates DER impacts on the distribution and transmission grid.[xliv] This tool integrates GridLAB-D for distribution system modeling, GridDyn for transmission system modeling, DER-CAM for DER adoption and dispatch optimization, and visualization of the feeders and measurements.

4.7.2 Advanced Functionality Needed

With the increasing adoption of DER in distribution systems, integrated T&D models are needed to optimize the size, location, and type of DERs, but these models currently exist only in a research setting and do not exist for commercial applications.

In general, the number of potential scenarios to consider in optimizing the sizing, siting, and type of DER is challenging. An exhaustive analysis, required for optimizations, is computationally intensive when many scenarios are being considered in large distribution systems with high numbers of DERs. Currently, no commercially available tools exist for optimizing the type, number, size, and location of DERs needed to achieve specific objectives in distribution systems or T&D systems.

Table 9. Advanced Optimization Tools and Methods for Distribution System Planning

Capability	Tools and Methods*	Advanced Functionality Needs
Identify the optimal type, siting and sizing of DERs that will achieve planning and operations objectives.	• Customized scripts can be added to typical distributions system analysis tools to achieve single variable optimization. • HOMER, DER-CAM, ReOpt can optimize DERs within a campus or microgrid based on balance of energy questions.	• Optimizing type, number, size and location of DERs at the distribution scale based on engineering analysis. • Characterizing T&D integration impacts and impacts of advanced technologies such as demand response, electrification and energy storage. • Incorporating power flow analysis to provide insights into voltage levels, power factors and line losses.

*Not an exhaustive list

[6] Phase I GMLC project 1.3.5 consisting of: Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, SLAC National Accelerator Laboratory, National Renewable Energy Laboratory, Brookhaven National Laboratory and Argonne National Laboratory.

5.0 Technologies and Applications that Factor into Distribution System Planning Analysis

The distribution system is changing. There are an increasing number of new devices, technologies, and control applications that can impact system operations and planning decisions. Many of these devices and applications exist at the grid edge—located closer to end-use customers (at homes, businesses, or at distribution systems very close to both) rather than at power plants or along transmission lines.[xlv] These devices and technologies create complexity and variability, but also provide new opportunities for distribution operations. Often, there are multiple approaches for these new components. This can provide additional options for distribution operations, but it can also multiply the variability and complexity in the planning analysis. In some cases, these devices and technology applications can be explored in existing distribution system analysis tools through an add-on module that is commercially available. In other cases, custom code needs to be developed and applied to traditional distribution system analysis tools. Additionally, in some cases, there are designated models or tools that are used to characterize these devices or technologies individually and whose results are then used as input to more traditional analysis and planning tools. This is true in the case of smart inverters, energy storage, transactive energy applications, and microgrids.

This section discusses the analysis needs and tools—now and in the future—of these devices, technologies, and control approaches.

5.1 Smart Inverters

The Institute of Electrical and Electronics Engineers (IEEE) defines an inverter as “a power electronic device that converts DC power from the primary energy source to AC power suited to the grid.”[xlvi] The primary purpose of an inverter is to covert the direct current from a solar PV array or other distributed generation resource to an alternating current for interconnection with a local load or the utility grid. Advanced, or smart, inverters have additional functionality that can help manage the impacts of distributed generation to the grid. The advanced functionality has the potential to support increased hosting capacity, increase the DER’s locational value, and help maintain overall grid reliability and power quality.[xlvii] In recent years, grid support features of modern PV inverters have become codified into standards at the state and national levels.

To fully assess the potential of new inverter functionality, distribution system planning models need to include these new, advanced inverter characteristics so that utility planners can evaluate possible benefits that new smart inverter functionality can provide. Although different models and analyses exist for evaluating various scenarios and uses of smart inverters, gaps exist because many commercially available tools are not able to model <u>all</u> new smart inverter functions.

The need for accurate secondary circuit models (from the transformer to the home) is fundamental in assessing smart inverters’ benefits related to providing dynamic reactive power (Volt-var) and mitigating voltage violations (Volt-watt control). Utilities do not have detailed secondary circuit models based on actual data because of the sheer number of discrete utility connections, and there was no way to measure it. However, with advanced metering, utilities now have actual data to use.

In addition, the sheer number of regulating devices on a system is growing, leading to more complexity. Typically, a utility might have between one and five regulating devices on a circuit, but with customer-owned DER, that number can increase into the thousands. This causes the models and simulations to become more complex to solve and requires more robust tools.

5.1.1 Tools

Utility planners can use traditional distribution system analysis tools to evaluate how smart inverters might mitigate impacts from DER, either by running the current, standardized smart inverter functions (e.g., Volt-var curves, Volt-watt curves) in power flow analysis or by writing custom scripts to interface with current distribution system analysis tools. However, as of the publication of this document, not all smart inverter functions can be modeled.[xlviii] This is a significant gap for distribution modelers.

Bulk system dynamic modeling tools, such as Power System Simulator for Engineering (PSS/E) and Positive Sequence Load Flow (PSLF), can model functions, including voltage and frequency ride-through and frequency response/regulation. However, these tools are typically used for bulk system analyses, and models typically do not have sufficient network detail to accurately model inverter impact at the distribution system level. PRECISE™ (Preconfiguring and Controlling Inverter Set Points), a tool[7] developed by NREL under a cooperative research agreement with the Sacramento Municipal Utilities District, can optimally select smart inverter voltage regulation settings (Volt-var and Volt-watt curves) based on the utility's distribution circuit information geographic information system (GIS) data, AMI data, and other inputs. The tool can automatically interface with Synergi and GIS.

5.1.2 Advanced Functionality Needed

Specific gaps for modeling smart inverters in distribution planning tools include the following:

- Inability to model all smart inverter functions.
- Ability to evaluate many discrete voltage-regulating devices (i.e., smart inverters and other more traditional devices) connected to a distribution circuit with a large number of smart inverters and operating independently.
- Lack of specific inverter device information necessary to develop models that produce accurate results.
- Ability to accurately model fault response for protection.
- Lack of accurate secondary circuit models that provide detailed inverter terminal voltage to accurately simulate Volt-var and Volt-watt control.

DOE could provide support in developing standard models for different types of inverters. Manufacturers could then provide parameters that could be used with the standard models in analysis tools. Such standard smart inverter models currently do not exist, and tool developers and utility planners are at a disadvantage in instances where manufacturers do not provide the information.

[7] https://www.nrel.gov/grid/precise-tool.html

Table 10. Smart Inverters in Distribution System Planning

Device Functionality	Analysis Tools/Methods*	Advanced Functionality Needed
Converts from DC to AC power, and helps manage voltage and frequency to mitigate issues, including those caused by DER.	• Standardized smart inverter functions can be run with traditional distribution system analysis tools using custom scripts. • PRECISE is a tool designed to interface with existing dynamic system analysis tools and GIS, as well as to optimally select smart inverter settings.	• Capability of modeling all smart inverter functions. • Robust tools that reduce the computational burden of modeling many smart inverters operating independently. • Protection models that accurately simulate fault response. • Manufacturer inverter information available to tool developers.

*Not an exhaustive list

5.2 Energy Storage

As the amount of renewable energy on the grid increases, energy storage will become increasingly valuable to smooth out the use of renewable energy over the day and to support grid reliability and resilience. Evaluating energy storage in distribution system planning requires the modeling and evaluation of the technology's different operational characteristics and value streams. At present, due to the its complexity and relative nascent nature of the technology, it is difficult to model and characterize the opportunities provided by energy storage.

There are three different categories of energy storage tools relative to distribution system planning: (1) distribution system analysis and power flow analysis tools, (2) valuation tools that look at the economics of different battery systems in different market and operational contexts, and (3) tools for locating and sizing energy storage systems.

5.2.1 Tools

5.2.1.1 *Power Flow Tools*

Evaluating energy storage impacts to power flow for system planning can include a combination of snapshot, time series, and dynamic simulation. Which method a utility uses will depend on the application scenarios, the level of detail needed in the results, and the planner or researcher's area of interest (what time scale: static, time series, or dynamic). Different simulations look at different time frames and utilize different modeling tools.

Snapshot simulations are a more rudimentary approach for evaluating storage systems and allow utilities to look at one instance in time. With this method, storage is modeled as positive load when charging and negative load when discharging. All existing common distribution system analysis tools can perform energy storage snapshot simulations.[xlix] However, the benefits and insights gained from snapshot modeling for batteries are limited. Time-series analysis provides more details about system behavior under different load, supply, and battery charging and discharging conditions at user-defined time steps. The EPRI-developed tool, OpenDSS, also models energy storage functions in power flow analysis for distribution systems in both snapshot and time-series modes.

Dynamic simulations allow utilities to observe impacts that happen in the seconds to microseconds time-frame and include electromagnetic dynamics and electromechanical dynamics. Dynamic simulations are useful for evaluating reliability, power quality, and protection. Energy storage systems with various control modes are usually evaluated in

PSCAD,[l] an electromagnetic solver, to evaluate their stability performance in dynamic simulations.[li] To study the impact of energy storage on large power systems, the commercial software PSS/E[lii] and PSLF[liii] are commonly used for electromechanical dynamic studies in transmission systems.[liv] Western Electricity Coordinating Council has provided the generic model of energy storage systems that can provide frequency regulation and voltage support.[lv, lvi] Several distribution system analysis tools are also capable of simulating electromechanical dynamics behaviors of energy storage systems with user-defined models.[lvii, lviii, lix]

Each of the different analysis types will provide the utility with different insights. Snapshot simulations allow the utility to look at one specific grid and battery condition. For example, during peak load when the battery is discharging or at minimum load conditions with the battery charging. While snapshots provide the utility some insight, they have limited practical usefulness. Time series simulations, on the other hand, provide a more realistic assessment of how conditions, and therefore the benefits, change over a given time period. Utilities can use these simulations to evaluate different charging and discharging patterns, and dynamic simulation gives information about inertia, frequency, and very short time-frame fault behavior.

5.2.1.2 *Valuation Tools*

There are several specific energy storage valuation tools that exist; however, none of them are currently capable of evaluating the full range of use cases and associated values streams of energy storage, nor are they able to perform co-optimization analyses to estimate the maximum value provided by each service.[lx]

Some of the current battery storage valuation tools that exist include: (1) Storage Value Estimation Tool (EPRI), (2) Energy Storage Selection Tool (DNV GL), (3) Battery Storage Evaluation Tool (PNNL), and (4) Energy Storage Computational Tool (Navigant). Each of these tools generally optimize across a limited number of use cases, ignore electrical system and market effects, and tend to use simplistic representations of internal state.

5.2.1.3 *Location and Sizing Tools*

DER-CAM from LBNL, ReOpt from NREL, and the commercial tool HOMER identify the optimum sizing and location of energy storage in campus or microgrid settings. All of these tools can recommend sizing and locations based on a discrete set of potential battery storage value streams. As the value streams of battery storage are further characterized and operationalized, additional tool functionality will be needed to model the full set of potential energy storage value streams that will be used as the basis for locating and sizing battery systems. Additionally, tools are needed that support this functionality for the distribution system as a whole and not just at the campus and microgrid level.

For existing distribution system analysis tools to include storage in a way that would support location and sizing, battery system models are needed that can be integrated, through custom programming, into the distribution system analysis tools.

5.2.2 Advanced Functionality Needed

Gaps exist for energy storage tools in all three categories.

- Power flow modeling and traditional distribution system analysis tools: While energy storage modeling capabilities are not included in traditional power flow models, tool vendors indicated that at present, there are not a lot of requests to include them.

Additionally, they reported that obtaining models of individual battery systems needed for detailed simulations have been difficult or impossible to obtain from battery manufacturers. This is not a significant challenge at present, but as more battery systems are installed in distribution systems, the need for both battery system models and incorporation of battery systems in distribution system analysis tools will increase.

- Valuation tools: No single tool provides a comprehensive representation for assessing all valuation streams, so utilities tend to use different tools for different valuation needs. Therefore, individual model limitations prevent a utility from understanding the complete picture of the value potential of energy storage to the grid. Another gap is that there is no single tool that can address a variety of use cases to co-optimize across the entire system (i.e., bulk energy system, ancillary services, the transmission system, the distribution system and customer energy management). Gaps also exist relative to tools that can estimate electrical system effects and market impacts due to the operation of an energy storage system. In addition, there are gaps in tools that include a more comprehensive picture of the internal state of the battery, including thermal effects, degradation, and interdependencies.[lxi]
- Location and sizing tools: Expanded versions of optimization tools—such as DER-CAM, ReOpt, and HOMER—that include a full range of value streams and can be used at scales beyond campuses or microgrids. Battery system models from manufacturers are also a gap in incorporating batteries into traditional distribution system analysis and planning. Also, although different software exist that perform desktop optimizations, there is a gap in translating those optimizations into controllable dispatch algorithms that can be operationalized.

Table 11. Energy Storage in Distribution System Planning

Device Functionality	Analysis Tools/Methods*	Advanced Functionality Needed
Stores energy to supply energy, as well as provide support services to the grid.	• Commercial and research tools can model charge/discharge behavior or battery storage systems with custom programming. • Energy storage valuation tools exist: SVET, ESST, BSET and ESCT. • DER-CAM, ReOpt, and HOMER support sizing and locating energy storage devices at campus and microgrid scale.	• Designated storage modules in commercial power- flow tools. • A battery valuation tool that represents all the value streams of storage and addresses a variety of use cases. • Distribution scale tools that support locating and sizing battery systems. • Specific battery storage system information from battery manufacturers.

*Not an exhaustive list

5.3 Flexible Loads

Flexible loads can be integrated into distribution system planning together with supply side resources and can often be part of NWA schemes. Demand response and transactive energy are two forms of flexible loads. DOE defines demand response as “a tariff or program established to motivate changes in electric use by end-use customers, in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized.”[lxii] Transactive energy systems include the ability to manage buildings as energy assets that can be used beneficially to provide real and reactive power, responsive demand, peak-load management, dynamic load shaping, ramping capabilities, and energy storage.

5.3.1 Tools

Two categories of flexible demand tools are discussed in this section: (1) tools related to demand response and (2) tools specific to transactive energy.

5.3.1.1 *Demand Response Tools*

In distribution system planning, utilities typically perform manual projections for peak-load impacts of demand response programs. These can be based on the existing and planned numbers of customers in their service territory, as well as the historical performance of each type of demand response program, which can be extracted from individual program load impact evaluation reports. Non-peak impacts of demand response can also be projected manually for each program based on time of day, day of week, and expected temperature profile.[lxiii] No specific tools are required to consider demand response in this way.

For a more sophisticated analysis beyond simply reducing peak load based on projected impact, demand response can be incorporated into power flow analyses through the use of custom scripts, but there are no ready-made modules that support the modeling and analysis of demand response in the tools commonly used in the United States. However, one commercial tool vendor who consulted in the development of this report is currently working on adding demand response capabilities to their traditional system analysis tools. GridLAB-D, an open-source research tool that models end-use appliances, is capable of directly conducting demand response studies and evaluating the effects of demand response on the utility distribution system and utility revenues.[lxiv] One commercial tool, DPG.sim, was developed by Adaptricity in Switzerland and can perform distribution grid power flow analysis, including the effect of demand response programs; however, it is less common and not widely used by utilities in the United States.

5.3.1.2 *Transactive Energy Tools*

Analyzing the potential physical and financial effects of transactive energy on a distribution system requires detailed modeling of the distribution system loads and components. Utilities can use TSPFA, in conjunction with other tools (such as building simulation models, software agents, and communication system models), to study grid interactions with customer-sided resources. As more of these customer-owned resources are able to participate in markets, they need more consideration during planning because they could significantly impact operations. They also have the potential to impact utility communication systems.

Transactive Energy Simulation Platform is an open-source platform (TESP 2018) that integrates multiple simulation modules, including GridLAB-D for distribution system simulations, MATPOWER for bulk system simulations, and EnergyPlus for large commercial building simulations. The integrating FNCS is used to manage time step synchronization and message exchange among all federated simulation modules in Transactive Energy Simulation Platform.[lxv]

The National Institute of Standards and Technology (NIST) has a complete inventory of tools that can be used for modeling transactive systems, and they are listed on the NIST transactive energy challenge website (https://pages.nist.gov/TEChallenge/toolchest/toolstable/). The list includes non-commercial tools (e.g., GridLAB-D, OpenDSS, Modelica, AMES, and EnergyPlus), commercial simulation tools (e.g., OPAL-RT, RTDS, ETAP, Promod, PSSE and PSLF, and UPLAN), and co-simulation platforms (e.g., HLA, FNCS, C2WT, FMI/FMU, DIS, and CRex).

5.3.2 Advanced Functionality Needed

Although a handful of successful transactive energy pilot projects have been completed, for transactive energy to be considered in distribution system planning, tools for modeling need to mature and develop. Currently, modeling of transactive energy systems is an emerging area limited to research organizations (universities and national laboratories). Before transactive energy can be incorporated into operational distribution system planning, effective, properly established short-run marginal costs or other price signals are needed to achieve a market-based provision of DER products and services.

Future functionality is needed in the following:

- Commercial tools that incorporate flexible loads into power flow analysis.
- Commercial tools that factor in market-activated flexible loads and the associated short-run marginal costs or other price signals.

Table 12. Flexible Loads in Distribution System Planning

Functionality Provided	Analysis Tools/Methods*	Advanced Functionality Needed
Ability to increase or decrease loads based on needs of utility.	• Peak reduction impacts are calculated manually by utilities. • Custom scripts can be used with traditional distribution system analysis tools. • GridLAB-D and DPG.sim can directly assess impacts of demand response programs. • Research co-simulation platforms link TSPFA with building simulation and market models.	• Commercial tools that incorporate flexible loads into power flow analysis. • Commercial tools that factor in market-activated flexible loads and the associated short-run marginal costs or other price signals.

*Not an exhaustive list

5.4 Microgrids

A microgrid is a group of interconnected loads and DERs within clearly defined electric boundaries that act as a single controllable entity with respect to the grid.[lxvi] Microgrids are being considered an approach for increasing resilience for critical loads, such as hospitals, or for important loads during an emergency, such as shelters. Industries with high reliability needs, like micro-chip manufacturing, are also considering microgrids. Utilities are running microgrid pilot tests to evaluate their use. Although the number of systems in place is small, they are not an important aspect in planning at this time. As microgrids that can island from the main distribution grid become more common in the future, modeling these systems will need to be incorporated into distribution system planning.

5.4.1 Tools

There are two categories of tools with regard to microgrids that are described here. The first category is microgrid specific tools that are used to develop controls and optimize system resources within a microgrid itself. The second category is broader distribution system-wide analysis tools that include islandable microgrids in order to determine the impacts of microgrid operations on the overall system.

5.4.1.1 *Microgrid Specific Tools*

Modeling microgrids has the same challenges as modeling DER in general, but the underlying source strength of the grid is not there or is significantly reduced, in the case of microgrids. Research and development facilities at universities, national laboratories, and specialty consultancies can perform detailed analyses of microgrids using transient programs that address large deviations in frequency, voltage, and balance between phases. Dynamics modeling for microgrids is a research area and a gap in commercial tools.

DER-CAM, ReOpt, and HOMER are tools that can be used for microgrid design and analysis. Microgrid Design Toolkit, developed by Sandia National Laboratories, aids in the design of microgrid systems. ROMDST (Remote Off-grid Microgrid Design Support Tools) is a tool that supports the design of remote microgrids.[lxvii] Other microgrid design and operations tools are under development at research organizations and national laboratories.

5.4.1.2 *Broader Distribution System Analysis Tools*

Microgrids can be modeled as components in the distribution system in research distribution system analysis tools, such as OpenDSS and GridLAB-D. However, microgrids are not represented in commercial distribution system analysis tools. Some of the commercial distribution system analysis tool vendors that consulted in the preparation of this report indicated that modeling of microgrids themselves and the microgrid controllers within traditional distribution system analysis tools that utilities use (CYME, Synergi, Milsoft) is only in the conceptual phase at this point and limited to research and development.

If microgrids are to be included in larger distribution system analyses, simplifying assumptions or custom codes must be developed to represent microgrids in simplified forms and/or the co-simulation platforms used.

5.4.2 Advanced Functionality Needed

The following gaps exist for microgrids:

- The ability to dynamically model microgrids in commercial distribution system analysis tools.
- Co-simulation tools that link microgrid specific tools to distribution system analysis tools.
- Real microgrid data that could be used for testing is a gap to tool development.

In addition, tool developers need standards to model controllers in an islanded mode. While there are some relevant IEEE standards for microgrids, such as the microgrid controller testing standards that came out in 2017 (IEEE 2030.7-2017), a new microgrid standard is in the early stages of development (P2030.12) and is a guide for the design of microgrid protection systems. Full development of the new microgrid protection standard could take up to four years. This is a gap.

Table 13. Microgrid in Distribution System Planning

Functionality Provided	Analysis Tools/Methods*	Advanced Functionality Needed
A group of stand-alone, or islandable, interconnected loads can operate independent of the bulk grid.	• HOMER, Microgrid Design Toolkit, ROMDST, DER-CAM, and ReOpt. • Research tools at universities, national laboratories, and specialty consultancies.	• Dynamic modeling of microgrids in commercial tools or commercial co-simulation tools that link microgrid tools with traditional distribution system analysis tools. • Real microgrid data for testing and tool development.

*Not an exhaustive list

5.5 EVs

Increasing numbers of EVs and EV charging stations will impact the timing and location of load that must be served and evaluated in distribution system planning. There are two aspects that must be considered: (1) deployment level of vehicles and (2) the amount of charging. Utilities currently use their own EV projections combined with traditional planning tools to forecast the impacts of EVs on system load. Bass-diffusion modeling for EVs is being used to forecast EV adoption. For example, Xcel Energy in Minnesota is adjusting residential load and system peak demand to account for projected adoption of light-duty EVs that was developed “based on an internally-developed methodology that incorporates both economic payback and Bass-Diffusion (technology adoption) model.”[lxviii]

EV forecasts are being developed internally by Xcel based on assumptions related to both adoption and charging behavior. Data that is input into Xcel’s adoption model includes: electricity prices, vehicle battery prices, gasoline prices, car ownership, car usage, and battery efficiency. Assumptions are made about the share of charging done at home and the number of managed charging stations. The charging behavior was estimated by Xcel using data from Idaho National Laboratory’s EV Project. Xcel modeled a low and high scenario cases.[lxix]

5.5.1 Tools

The tool LoadSEER includes agent-based modeling of EVs and can help support utility planners by providing information about how EVs will change future peak coincident load hours. It does not project EV adoption, but it does use EV adoption numbers to reveal system impacts.[lxx] Kevala’s EV Assessor (https://kevalaanalytics.com/ev-assessor/) can be used to optimize EV charging infrastructure, inform rate design, and evaluate the impact of given EV projections.

NREL’s Electric Vehicle Infrastructure Projection Tool (EVI-Pro) is a tool for projecting consumer demand for electric vehicle charging infrastructure. utilities and policymakers can use the tool to identify the number, type and location of needed EV charging infrastructure.[lxxi]

The model BEAM, developed by LBNL, is a “Modeling Framework for Behavior, Energy, Autonomy, and Mobility.”[lxxii] BEAM includes the ability to analyze energy impacts of changing mobility trends generally, as well as the potential impacts of EV adoption and the benefits of managing charging to support grid reliability and the flexible provision of energy services.[lxxiii]

POLARIS (https://www.anl.gov/es/polaris-transportation-system-simulation-tool), developed by Argonne National Laboratory, is an open-source, agent-based transportation simulation tool that can be used to estimate the impacts on mobility at the regional level. It can evaluate the energy impact of vehicle and transportation technologies, including EVs from a small neighborhood to metropolitan area scale.

Both BEAM and POLARIS could be combined with internally-developed utility projections and tools to understand impacts of EVs.

5.5.2 Advanced Functionality Needed

There are stand-alone regional mobility/transportation focused tools available, such as BEAM and POLARIS, but current distribution system planning tools do not yet offer add-ons or modules focused on EVs. Comprehensive tools that project adoption and charging behavior of different types (light-duty, medium-duty, and heavy-duty) of EVs in a utility service territory are not commercially available. There are also gaps related to EV manufacturer information that can be used to model EVs in power flow simulations.

Table 14. Electric Vehicle in Distribution System Planning

Functionality Provided	Analysis Tools/Methods*	Advanced Functionality Needed
EV battery charging is a significant new load that distribution planners need to plan for. Eventually vehicle to grid services can support the distribution system.	• LoadSEER includes agent-based modeling of EVs. • Kevala EV Assessor supports design of EV charging infrastructure. • EVI-Pro provides guidance of charging infrastructure needs. • BEAM and POLARIS are mobility focused tools that can be used to address impacts of different EV levels. • Utilities are developing customized Bass-Diffusion models to project EV adoption. • Research tools also exist.	• Commercial tools for projecting EV adoption and charging behavior that can be used for distribution system planning and operations with EVs. • Specific EV manufacturer information that can be used in modeling.

*Not an exhaustive list

6.0 Conclusion

Distribution system planning is ultimately about supporting investment decisions that allow a utility to maintain system safety and reliability at a reasonable cost. The increasing number of DERs connected to the grid is changing how utilities perform their distribution planning process. Growing DERs increase the number of potential options and solutions to evaluate, which is increasing complexity and cost of planning. Effective integrated distribution system planning addresses the costs and benefits of DERs, is integrated with resource and transmission planning, and can support the evaluation of deferring traditional infrastructure investments. However, successful distribution system planning with DERs requires investments in data collection, as well as new tools and practices.

The primary issue preventing enhanced, integrated distribution system planning is the lack of existing, relevant data. The data needed for modeling feeders, loads, and DERs are not always available. Data can exist in different departments at a utility, with third-party developers, or equipment manufacturers. Data can also be functionally locked within different proprietary software programs. Standardized and fungible data formats are needed. Identifying and prioritizing data needs, identifying data gaps, and developing strategies for filling data gaps are essential early steps when choosing modeling tools and guiding investment decisions.

Advanced analysis requires accurate, detailed feeder models, which requires documenting the utility's distribution system, including capturing ongoing field changes, to make sure that the electronic models are up to date and represent the current state of operations.

As distribution system planning evolves so are the planning tools available to utilities; however, gaps exist that would allow utilities to better evaluate grid conditions, available options, and solutions. Tools that are needed are that:

- Support options analysis to incorporate flexibility and emerging technologies into roadmaps and investment plans;
- Develop grid architecture-based grid observability strategy, including the design of sensors and communication systems;
- Develop and evaluate different DER deployment scenarios and policies and automatically update projections based on deployment patterns;
- Move beyond hosting capacity screens and automatically generate solutions, including controls, capacitors, battery storage systems, reconfiguring circuits, or demand-side solutions, when hosting capacity or interconnection analyses identify an issue;
- Simulate distribution systems with multiple devices, such as smart inverters and energy storage, simultaneously operating autonomously and tying physical grid impacts with DERs to context-specific economic value; and
- Incorporate market-activated flexible loads into power flow analysis and the associated short-run marginal costs or other price signals.

New tools with capabilities to evaluate and plan for the increased complexity, new technologies, and various operating schemes will assist utilities and policymakers as they plan and evaluate future options.

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