Urban Networks Simulation Tools

1017690

Urban Networks Simulation Tools

1017690

Technical Update, March 2010

EPRI Project Manager
M. Olearczyk

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Citations

This document was prepared by

Electric Power Research Institute (EPRI)
1300 West W.T. Harris Boulevard
Charlotte, NC 28262

Principal Investigator
R. Dugan

This document describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Urban Networks Simulation Tools. EPRI, Palo Alto, CA: 2010. 1017690.

Product Description

Utilities that serve customers using networked secondary, or low-voltage, systems require that technologies be able to model the system and perform load flow and other circuit analyses on both the primary and the networked secondary. Utilities can use commercially available load flow products to model their radial systems, but many older products are unable to accurately model and perform analyses on meshed secondary network systems sourced from multiple primary feeders. Consequently, many utilities are using legacy systems to perform network analyses—systems that might lack ties to geographic information systems, graphical display ability, ability to easily analyze what-if scenarios, ability to reflect real-time system condition changes, and other features of newer, vendor-developed products.

Results and Findings

Seven of the 10 vendors of distribution system analysis software surveyed responded that they can analyze highly meshed urban networks. This is a higher percentage than was expected. Because vendors seldom develop capabilities without demand from their users, this is likely a sign that several utilities have been requesting urban network modeling capability. This should mean that utilities now have more choices of tools.

Challenges and Objectives

One key problem is actually proving a vendor's claims without resorting to an expensive trial usage. There are few, if any, publicly available benchmark systems for urban network analysis. This provides a loophole in which vendors can promote vaporware, hoping to develop the capability before they actually have to deliver. This is not necessarily a reason to reject a software product. Knowledge of how to do this analysis and software for the basic mathematics are readily available. Therefore, it is possible for vendors to implement these capabilities relatively quickly if the product has other desirable features. However, potential users should perform their due diligence before purchasing one of these products in order to verify that the tool is suitable for their networks. It is recommended that the Electric Power Research Institute (EPRI) support industry efforts to produce urban network benchmarks.

Application, Value, and Use

Utilities can benefit from assistance in understanding what vendor products are currently available to model and perform analyses on network systems and what features are contained within these products.

EPRI Perspective

EPRI views this research as meshing with a number of programs involving advanced distribution system analysis. EPRI personnel have extensive knowledge of this area and personally know key vendor representatives. This has enabled EPRI to receive ready cooperation from most of the vendors of interest. EPRI also has some experience developing distribution-oriented tools with the capabilities of modeling urban networks through its publicly available OpenDSS simulation software. By making this tool open source, EPRI's goal is to make the knowledge for analyzing urban networks more widely dispersed, ultimately leading to more choices for EPRI members for tools with this capability.

Approach

The primary goal of the project was to provide a snapshot of the state-of-the-art of commercial tools for urban primary and secondary network analysis. Custom-built programs were not evaluated in this project. EPRI, with the assistance of its advisers, identified several commercially available distribution-oriented tools for modeling network systems and performing network circuit analyses. A list of desired features was compiled. Items of interest included graphical displays, ability to perform primary feeder fault analysis, ability to perform networked secondary load flows, ability to perform power quality analyses, and interfaces with mapping systems, geographic information system data, advanced metering infrastructure (AMI) data, customer information system data, and supervisory control and data acquisition (SCADA)/remotely monitored data to create accurate network models. A questionnaire was compiled and sent to the vendors identified. The responses are included in the appendices of this report. The number of vendors responding in the affirmative (7 of 10) was higher than expected. Additional information was compiled from EPRI's Systems Studies group, which has experience with some of the tools available. For one tool, information was supplied by a utility user of the software.

This report presents background information on distribution system analysis to provide a basis for comparing the tools. EPRI's OpenDSS software is used as a reference benchmark throughout. Next, a summary of the various tools from the perspective of the Principal Investigator is provided. Finally, a matrix of vendor product offerings with available features that support network planning, design, and operations is presented. Because some utilities use transmission system analysis tools for studying urban networks, evaluations of a few transmission tools are also included in this report.

Keywords

Distribution system analysis
Low-voltage (LV) networks
Meshed network analysis
Secondary networks
Urban networks

Acknowledgments

The Electric Power Research Institute (EPRI) would like to thank Con Edison of New York and NES of Nashville, Tennessee, for contributing urban network examples for this project.

Contents

List of Figures

List of Tables

1 INTRODUCTION

Utilities that serve customers using networked secondary systems, also known as *urban low-voltage (LV) networks*, require technologies to be able to model both the primary and secondary systems. Many commercially available distribution system analysis products are available to model radial distribution systems. However, many older products are unable to accurately model and solve meshed urban LV network systems sourced from multiple primary feeders. Utilities have resorted to various tactics to fill this void. Some have written their own software, whereas others have frequently used transmission analysis programs to do power flow and short circuit analysis of networks. These systems lack features that distribution planners are accustomed to having in their distribution system analysis tools, including the following:

- Ties to geographic information systems (GISs)
- Geographically correct graphical display ability
- Ability to easily analyze what-if scenarios in a distribution context
- Ability to reflect real-time system condition changes
- Other features of newer, commercial vendor-developed products

Utilities can benefit from assistance in understanding what vendor products are currently available to model and perform analyses on highly meshed network systems such as urban LV networks. This report presents the results of a survey of 10 vendors identified by the project's advisory team and an assessment of the capabilities by the Principal Investigator, who has participated in industry activities in distribution system analysis for more than 30 years. This report provides Electric Power Research Institute (EPRI) members with the following:

- A summary of features that are important to members
- A description of what functionality is available in the marketplace and a means to ascertain whether the features of commercially available products will meet their needs, especially with respect to urban network modeling and analysis
- A matrix that shows features of commercially available products, including a matrix of transmission system analysis tools, to help utilities quickly evaluate vendors and select products

With these results, utility engineers and networked system operators will be able to compare the functionality of commercially available products to their specific network analysis and modeling needs. This comparison will help them develop a practical technology implementation strategy and prepare a justification for the investment in a vendor modeling and analysis software implementation and integration.

Ultimately, the implementation of appropriate network modeling and analysis software will help engineers develop optimum system reinforcement plans to meet capacity and reliability expectations. It will also aid operators in optimally configuring the system based on real-time conditions. These results are described with an eye toward the future, in which EPRI envisions distribution planning functions and real-time distribution operations functions merging. Tools are assessed on their potential to adapt to future needs as well as their present capabilities.

The project was carried out by sending a detailed questionnaire to the vendors identified by the advisors and by interviewing key participants in IEEE committees on distribution system analysis. One tool was assessed through an interview with a utility user. Seven of the 10 vendors surveyed returned responses.

Responses varied from detailed, specific responses to portable document format (.pdf) files of marketing literature. The responses to the survey questionnaire are included verbatim in the appendices. One response was truncated due to its length. These responses and the information gathered from interviews are described in Section 3.

All seven vendors who responded indicated that they could now handle highly meshed urban LV networks; none admitted that they could not. This differs from the perception of those involved in this project at its outset. The Principal Investigator was aware of only three of the 10 having the necessary capabilities, and one of those three did not respond to the survey. Therefore, one cannot conclude that failure to respond means a lack of capability. This surprising response is likely an indication that vendors are beginning to respond to user demands for appropriate capabilities for urban LV network analysis in a distribution-oriented package.

As with all important purchases, utilities considering a purchase of new software should carefully evaluate the claims of the vendor. The IEEE is developing benchmarks for comparing tools, but one for urban LV networks is not likely forthcoming before 2012. This could be one area in which EPRI members could contribute some support to accelerate progress.

Section 2 describes distribution system analysis methods in order to establish a basis for understanding the various approaches taken by the vendors participating in the survey. The EPRI OpenDSS program is used as an example in this section, and throughout the report, to establish a reference point.

Section 3 describes commercially available distribution system analysis tools. Section 4 provides a matrix of features of those tools, as well as a matrix of transmission system analysis tools.

Section 5 presents two examples of urban LV network analysis. One is a relatively small, down-town network in Nashville solved with the OpenDSS program. This is included with permission of Nashville Electric System and is a network that is included in EPRI's ongoing plug-in hybrid electric vehicle impacts project. The other is a network in Manhattan modeled in EDD's DEW program. This is an example provided by ConEdison.

Finally, Section 6 looks to the future to identify what features will be important a decade from now, and beyond, to support the vision of the SmartGrid and describes EPRI involvement in advancing distribution system analysis tools.

2 DISTRIBUTION SYSTEM ANALYSIS METHODS

The material in this section provides a brief tutorial on distribution system analysis methods to provide a basis for understanding the assessments of the various tools provided in Section 3 and the vendor responses presented in the appendices.

Radial Circuits

The vast majority of electric power distribution circuits are configured in a radial structure. That is, there is but one path from each load point back to a bulk power substation. The circuits are said to emanate *radially* from the substation bus. Thus, there is a distinct difference between this topology and that of the main subject of this report—meshed network distribution systems.

The primary reason that utilities around the world configure most of their systems radially is cost. Utilities have found they can achieve adequate reliability with this topology, and it simplifies operation. Short circuit fault protection can be accomplished with relatively simple, series overcurrent devices that can function independently from one another. Only one device must operate to clear a fault.

In contrast, in urban LV networks—or any meshed network, for that matter—at least two devices will generally operate to clear a fault. If the faulted element can be quickly isolated, the remainder of the network retains power and customers are not subjected to an outage. This provides a much higher level of reliability than with radial circuits, but at an increased investment cost.

Radial circuits can be solved with a wide variety of circuit solution techniques. Nearly any method that will work on meshed networks (circuits with closed loops) will solve radial circuits, as well. A commonly noted exception is the fast decoupled power flow algorithm of Stott and Alsac that is frequently used in the analysis of large transmission grids [1]. The problem is not as much with the radial topology as it is with the nature of distribution lines in which the resistance-to-reactance (R/X) ratio is high. The standard fast decoupled method essentially ignores the resistive (R) part of the line and transformer impedances, which makes the method fail to converge on some radial distribution systems. Some analysts—including the Principal Investigator of this project—have developed tricks to make the method work, but it is of limited advantage compared to the methods that are specifically developed for radial circuit analysis.

The special topology of a radial circuit lends itself to techniques that will not work on meshed networks. These techniques fall into the general class of *ladder techniques*. Most radial circuit solvers use some form of the forward and backward sweep method. The most common implementation is likely that described by Kersting [2]. Several variations are possible.

This technique mimics the manual voltage drop calculations that were performed by utility distribution engineers before distribution system analysis was computerized. The general method is illustrated in Figures 2-1 and 2-2.

Figure 2-1 shows the forward sweep, in which the voltage drops are computed from the source to the ends of the feeder. Often, for the first pass, the load currents are assumed to be zero. Thus, the first forward sweep initializes the voltages along the feeder. This sets things up for the backward sweep, in which the currents are estimated.

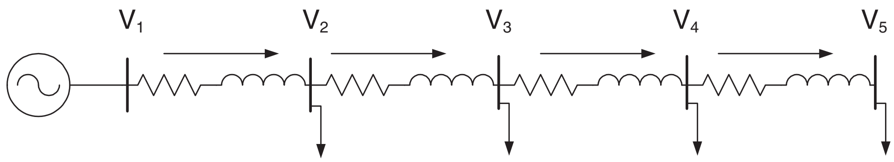


Figure 2-1
Forward sweep: Compute voltage drops from the source to the end of the feeder

After an estimate of the voltage is obtained for each bus, the load currents can be computed. These are then accumulated from the ends of the feeder back to the source. This is illustrated by the backward sweep in Figure 2-2.

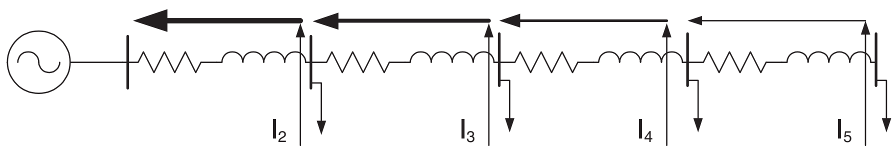


Figure 2-2
Backward sweep: Accumulate load currents from the end of feeder to the source

This process is repeated until the solution converges. Convergence can be determined by voltage, current, or power. It is usually sufficient to choose one of these quantities, although some analysts require convergence of more than one.

There are numerous variations on this scheme, with different advantages and disadvantages. One common variation is to use powers rather than currents in the backward sweep. Some claim that this offers improved convergence characteristics.

Forward and backward sweep techniques usually converge well for most distribution systems, as long as the voltages are near the normal range. The techniques are also computationally efficient, which is one of the reasons that they are so widely deployed. No large matrices are required, and the programming is straightforward.

One desirable feature of this method is that it can accommodate multiphase models as well as single-phase, positive-sequence equivalents. Some transformer connections require special algorithms to achieve solutions. Kersting gives several examples [2]. The method accommodates tap-changing voltage regulators quite naturally, which is also a desirable feature for distribution system analysis.

There are limitations to this method. For power flow, convergence is more likely to be achieved when the series impedance of the lines and transformers is substantially lower than the equivalent shunt impedance of the loads, capacitors, and so on. This is usually not a problem on the majority of distribution systems, but it can be a problem on heavily loaded systems. The number of iterations can increase with longer feeders that are heavily loaded. Commercial software vendors have developed their own tricks of the trade for dealing with this situation, as well as others that might occur.

The technique is generally not suitable for harmonic simulations. It fails to converge at frequencies where the equivalent shunt impedance is lower than the series impedance. This will occur when the system gets into resonance.

Thus, the technique cannot be used for all kinds of distribution system analysis, but it is used as the basis for many types of steady-state analyses, such as power flow, short circuit, feeder reconfiguration, and reliability.

Weakly Meshed Circuits

Some looped distribution systems have a small number of loops; some have only one. It is common for analysis tools based on forward and backward sweeps to extend the method in order to address these so-called "weakly meshed" circuits. The basic idea is illustrated in Figures 2-3 and 2-4.

Figure 2-3 shows a radial feeder with one closed loop added. The simple forward and backward sweep method would not work on this system because there is no distinct feeder end. The solution to this dilemma is shown in Figure 2-4. One of the connectors creating the loop is broken and replaced by equal and opposite current sources.

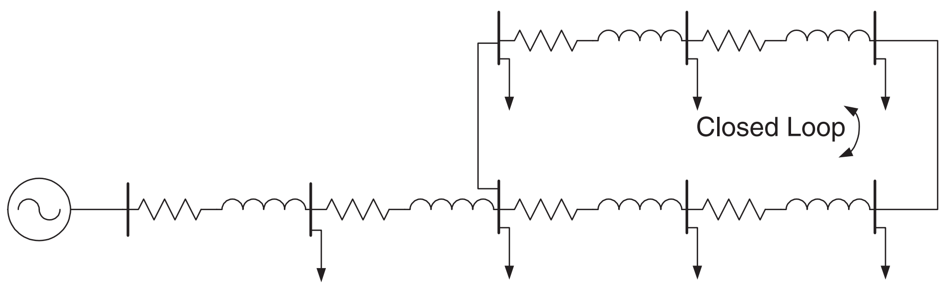


Figure 2-3
A weakly meshed distribution system with one closed loop

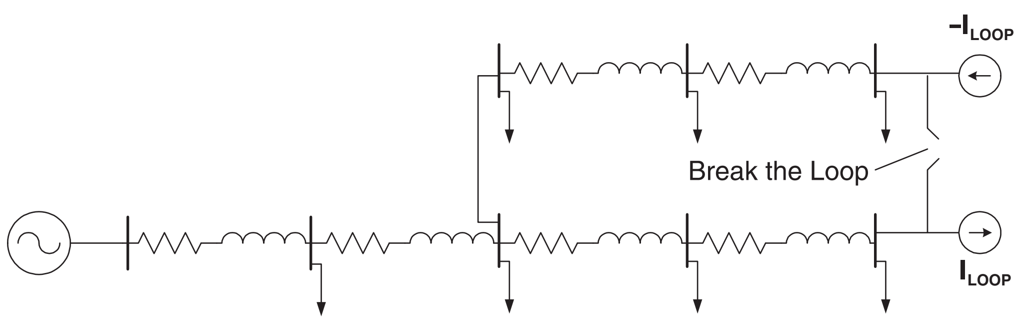


Figure 2-4
Opening the loop to solve with forward and backward sweep methods

This manipulation creates a radial circuit with what appears to be two additional, equal and opposite load current injections at the end. Thus, the conventional forward and backward sweep technique can be applied to the radial circuit. Then some extra equations must be written to produce values for I_{LOOP}. Numerous techniques have been proposed for this; they can be found in the literature on distribution system analysis by searching for the phrase *weakly meshed distribution systems*. The basic idea is to either force the two currents to be equal or to iterate until they are equal, depending on the technique.

A requirement of this technique to make it practical in the general case is to have an algorithm for searching out good places to break the loop or loops. Because the forward and backward sweep technique is a little touchy if a radial is overloaded, care must be taken to not leave a large load on one side of the loop point. For example, there might be a 10-MW load on a 15-kV class feeder at the point at which two sides of a loop connect. Although this might be perfectly serviceable when both sides of the loop are intact, it could grossly overload one side of the loop after the loop is broken. Therefore, the splitting algorithm must be smart enough to choose a sufficiently strong main path or to split the load between the two sides of the loop. This places quite a burden on the search algorithm when there are many loops and large loads, which is one of the main drawbacks to using this approach.

Nevertheless, several commercial programs successfully use a solution method of this kind to solve meshed network systems such as LV urban networks. One of the programs included in this project that uses a similar technique is EDD's Distributed Engineering Workstation (DEW) program. From papers based on this program's usage and from using the program for efforts related to this project, EDD has extended the graph theory concepts of *trees* and *cotrees* to enable the program to solve multiphase systems with multiple loops.

It is suspected that other commercial programs also use a similar power flow solution technique. However, the vendors typically consider their methods to be trade secrets due to the algorithmic customizations that they have made to ensure the method works, and they do not disclose them. Thus, we are left to speculation. Distribution analysts wishing to study LV urban networks should explore this issue with the vendors when considering purchasing a product. This is not to imply that such techniques cannot work for urban networks, but it is a recognition that programs that rely on weakly meshed solution techniques might struggle with the solution of urban networks more than do programs that were designed to solve highly meshed networks. Evaluation benchmarks should be requested. (The IEEE Distribution Test Feeder Working Group plans to produce a network benchmark in 2011 or 2012; the schedule is unclear at this time.)

Highly Meshed Network Methods

Because transmission systems are typically highly meshed, many utilities resort to programs such as PSS/E, PSLF, or T2000 to study LV urban networks. One drawback to this approach is that these programs typically assume a balanced system, using a positive-sequence equivalent model. Although this is sufficient for some planning issues, it is becoming increasingly important to analyze the effects of phase unbalance with the anticipated increase in large, single-phase loads such as electric vehicles and distributed resources. Distribution system analysis software vendors have begun to respond to this need by providing the capability to solve large urban networks with a more familiar distribution system analysis approach. Eight of the 11 distribution software vendors polled for this project now indicate that they have this capability. If this poll were to have been conducted 10 years ago, based on the Principal Investigator's knowledge of the capabilities, perhaps only one or two would have been able to make this claim honestly. Thus, there has been a relatively fast advancement in the state of the art of distribution system analysis software in the last few years.

Programs that are designed from the beginning for modeling large meshed networks in power systems generally use a solution formulation that lends itself to sparse matrix representation. The transmission system analysis programs will support a full Newton-Raphson power flow formulation [3], and most will also support a version of the Stott decoupled power flow [1]. The decoupled power flow is a derivative of the Newton-Raphson method. In some applications, the supposedly archaic Gauss-Seidel method [4] of solving the power flow equations, which has been omitted from more recent textbooks, is making a comeback with some analysts because it is more amenable to parallel processing. The Newton-Raphson method requires the formulation of a large Jacobian matrix, which is fortunately sparse. The Gauss-Seidel method can be programmed without forming large matrices.

The names *Newton-Raphson* and *Gauss-Seidel* have become synonymous with particular power flow formulations when stated in the context of power systems. However, they simply refer to general mathematical techniques for solving systems of nonlinear equations. It is only in the power industry that the names seem to be tied to the solution of a particular set of equations (that is, the standard positive-sequence power flow equations). These methods are not the only techniques that work on power flow formulations. For example, fixed-point techniques have also been found to work for distribution system power flow solvers. In fact, some forward and backward sweep methods are similar to fixed-point formulations, and some are essentially Gauss-Seidel formulations.

Likewise, the standard power flow equation formulations that are most often associated with the Newton-Raphson power flow method are not the only ways to formulate equations that yield the power flow solution. The traditional power flow equations, which can be found in nearly any power system analysis textbook, have been found to work well on transmission systems in which the nonlinearity of the system makes it difficult to solve. One of the key complicating factors is the presence of generation in the model specified by power and voltage (that is, PV buses). Distribution systems generally do not face this difficulty. Therefore, distribution systems can be solved with a wider variety of solution techniques.

One example of a different approach is EPRI's OpenDSS program. To maintain the flexible, multiphase modeling capability required for a research platform, the program simply forms a system nodal admittance matrix, Y, which is quite sparse for nearly all power system topologies. Nonlinear power conversion elements, such as loads and generators, are represented by Norton equivalents wherein the current source is a *compensation* current (see Figure 2-5).

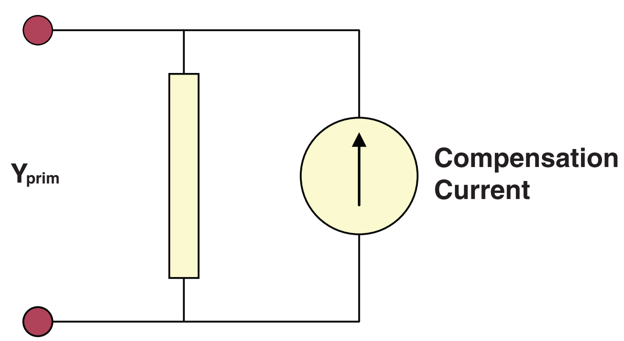


Figure 2-5
Norton equivalent load model used in the OpenDSS program

This approach is more closely related to techniques used in electromagnetic transients programs or harmonics analysis programs than in power flow programs. However, it works quite nicely for the vast majority of distribution system models, meshed or radial—no distinction is made. The default solution method is a simple, fixed-point iteration (see Figure 2-6).

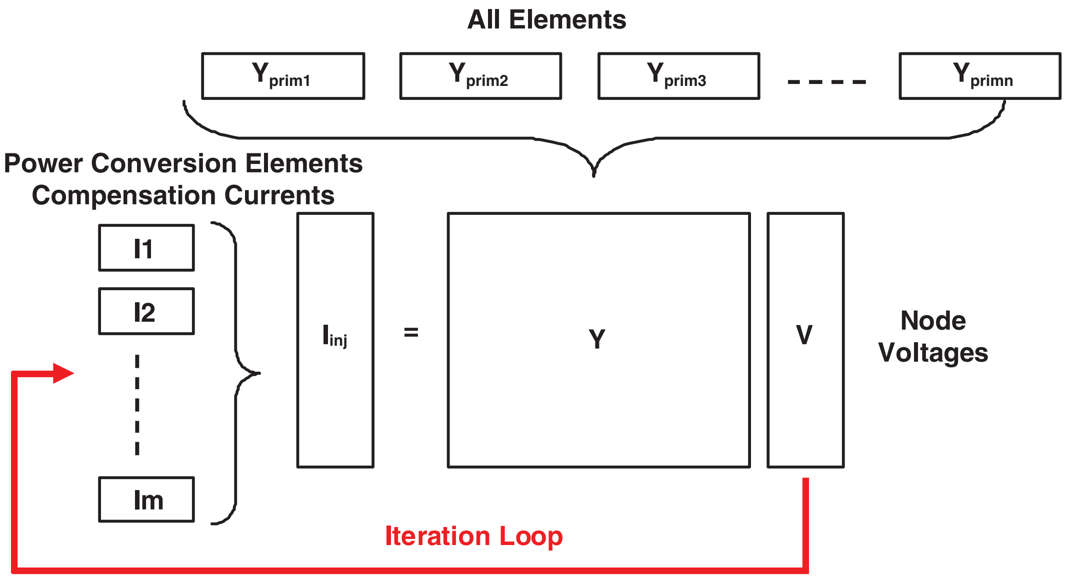


Figure 2-6
Fixed point solution algorithm used in the OpenDSS program

The system Y matrix is constructed from primitive nodal admittance matrices, Y_{prim}, for each element of the circuit. Each Y_{prim} embodies all the essential impedance characteristics of the element it represents. Thus, all system unbalances, mutual coupling, and strange connections of transformers are automatically included in the system model.

To solve this system of equations, the node voltages, V, are initialized to a best guess at the solution. This is either a so-called "flat start," computed by setting load currents to zero, or the results from the previous solution. The closer the voltages are to the final solution, the fewer the iterations required to achieve a solution. Next, the compensation currents are collected from each nonlinear device and added into the proper cell of the I_{inj} vector. The system of equations is then solved for the node voltages, V, using a standard sparse matrix technique. This process is repeated until the voltages converge to a solution. This typically requires no more than four or five iterations for a reasonably loaded distribution system. Many times, it requires only two, making it a desirable technique for annual simulations and the like.

This simple solution technique will work well most of the time for distribution systems—particularly, those with a dominant bulk power supply—and it has the advantage of computational efficiency. This is important when performing annual simulations and other simulations requiring many power flow solutions.

When the nonlinear elements in the systems cause the fixed-point solution method to fail to converge, a Newton method can be applied to the equations. This method is more tolerant of poorly converging systems because the partial derivatives in the Jacobian matrix generally continue to point in the direction the solution needs to go, even if the node voltages are further from the solution than ideal. The cost is that the Newton method requires approximately twice as many computations as the simple, fixed-point solution technique.

One benefit of the OpenDSS formulation is that harmonic flow analysis and short circuit analysis can be performed with the same set of equations. In fact, the program's electrical system formulation is closer to that of a harmonics analysis program than to that of a typical power flow program. A meshed network solver is often required for harmonics analysis, even if the power circuit is radial. With some additional capabilities, dynamics analysis is also possible because the formulation has features in common with some dynamics (transient stability) programs. When the program was initially developed, this was important for the modeling of distributed generation (DG) impacts. This formulation has continued to pay dividends as the program has been applied to a host of problems in leading-edge research in distribution systems analysis.

Another approach is that of researchers in Brazil who have devised the so-called "three-phase current injection method (TCIM)" approach to distribution system modeling [5]. Loads are modeled as multiphase current injections, analogous to that which is done in most forward and backward sweep methods. However, a large Jacobian matrix is formed instead of a radial tree, and the resulting set of equations is solved by Newton's method. This approach works equally well on meshed and radial systems, and it has certain advantages for modeling some cases with distributed generators that are otherwise difficult to solve. The TCIM program has many capabilities comparable to those of OpenDSS, having been developed for similar purposes. The two programs are frequently used to develop test feeder benchmarks for the IEEE Power and Energy Society (PES) Test Feeders Working Group.

Three of the software vendors who responded to the questionnaire in this project used language to describe their product that indicates that they, too, use a sparse Y matrix approach, similar to that described here. (See Section 3 and the appendices for vendor responses.) The methods for representing nonlinear elements and solving these equations is not known, but they are likely similar to the OpenDSS or TCIM strategies. When the vendor uses the term *current injection* (CI) along with *sparse matrix*, it is likely the same class of solution technique.

If the OpenDSS load model were a simple current source, rather than a complete Norton equivalent, the OpenDSS technique would be a CI method. The CI methods will generally work satisfactorily when the feeders are lightly to moderately loaded, although more iterations will be required in order to converge on a solution. In the Norton model, the admittance is included in the Y matrix, which gets the initial guess closer to the final solution. The current source part of the Norton model is a *compensation current*, which compensates for the difference in the load terminal current and the current in the assumed equivalent admittance. There is typically not much difference between the performance of a CI method and that of a compensation method for positive-sequence models. However, there can be cases in three-phase analysis where a simple CI method has poor convergence characteristics.

Sequence Network Equivalents Versus Full Three-Phase Models

Although programs traditionally used in transmission system analysis largely use positive-sequence equivalents, the state of the art in distribution system analysis is to use full three-phase (or *n*-phase) models. Urban LV networks are typically four-wire wye (star) systems. Thus, they can have significant unbalances that could benefit from full three-phase analysis.

One question that readers might have is "What are the ramifications of using transmission-oriented positive-sequence programs for studying my LV network?" The answer—as it often is—is that it all depends.

Positive-sequence equivalents generally work satisfactorily for basic distribution planning studies. Distribution planners usually do not plan for unbalance when planning for the capacity of the system. By allowing a little tolerance to the design, most of the adverse effects of unbalance can be accommodated using a planning model that assumes balance. If no other analysis is being done, the typical transmission analysis program will be adequate for solving balanced power flows on LV urban networks.

Transmission system analysis tools generally allow for the inclusion of zero-sequence impedance, which would enable the standard calculation of short circuit currents on LV urban networks if the zero-sequence impedances can be estimated.

The main drawback to using transmission tools for distribution system analysis is that engineers often wish to investigate other problems, such as unbalanced power flow, harmonic analysis, one- and two-phase lines and loads, fuse blowing, splice failure, energy efficiency, and DG protection. These problems often require a full phase-component model. Distribution planners are coming to expect such features in their tools for radial systems and to desire such features in network analyses.

Per-Unit Values Versus Actual Values

Transmission programs also typically take data descriptions in per-unit values and solve the network using per-unit values. In contrast, more than half of all distribution system analysis programs work in actual ohms, volts, and amperes. Some tools that were originally derived from transmission systems analysis programs appear to retain the per-unit and symmetrical component model inside, but distribution system analysis is moving away from this modeling technique because of the need to analyze a wider range of problems. Some examples that are difficult to handle in per-unit models are the following:

- The ubiquitous 120/240V split-phase service transformer. (This is more difficult in per-unit values than one might think.)
- Harmonics analysis is relatively straightforward when working in actual values. However, it is quite easy to make a significant error when attempting to do this in per-unit models, particularly if there is capacitive coupling between voltage levels.
- Short circuit faults between voltage levels, such as transmission overbuild falling into the primary distribution or primary distribution cables faulting into LV cables near the same manhole.

With modern computers, there is little justification for representing distribution systems in per-unit values. Many distribution planners are accustomed to seeing actual values in their tools. This is one objection to using tools designed for transmission analysis to model urban networks.

3 DISTRIBUTION SYSTEM ANALYSIS TOOLS

Status of Distribution System Analysis Tools

It is difficult to provide an accurate status update on distribution system analysis tools at any point in time because it is a rapidly changing area due to its being a highly competitive market. Also, increased interest in such things as the SmartGrid and distributed resources has triggered advancements in the capabilities of these tools. Because the tools are software, changes can be made rapidly when the idea is presented to an enterprising and capable programmer. As a case in point, it is highly likely that one of the vendors responding to the questionnaire distributed for this project developed network solution capability after receiving the questionnaire—partly to respond to the questionnaire and partly to respond to a request for quotation from a large utility. Thus, there is a fairly good chance that parts of this document will be obsolete before it reaches the reader. For the potential purchaser of software tools, this can be a good thing, because it means that the software of interest will have advanced capabilities that it would not have had otherwise.

When each of the commercial distribution system analysis tools was first developed, it fulfilled a perceived need and was likely implemented with close to state-of-the-art software techniques for the time in which it was developed. When a large user base is established, the accompanying inertia limits how quickly the vendors can implement new ideas. Later entries into the field are able to incorporate new features and leapfrog the competition on one or more fronts, whether it is data representation, user interfaces, or computational speed.

Many of the existing commercial packages can trace their heritage to transmission system analysis methods or to simple, manual voltage drop calculation methods. Therefore, they tended to support only positive-sequence models and per-unit models. This handicapped some vendors when, during the mid-1980s, there was a strong move to incorporate three-phase modeling and solutions. The demand for more detailed modeling accelerated in the 1990s, mainly due to the rising interest in DG. Those who came into the game at that time were able to start with three-phase modeling and bypass all the headaches involved in changing an installed base of software. Some of this will become evident as the capabilities of certain packages are examined later in this report.

It is the perception of many in the industry that, by the year 2000, distribution system analysis tool developers had become rather stagnant in their adoption of new capabilities and were resistant to change because of the user base inertia. EPRI has been participating in the IEEE PES Distribution Test Feeders Working Group since 2004 (the Principal Investigator chairs this working group). This working group develops benchmarks to test analysis tools, and one of its goals is to encourage suppliers of distribution system analysis software to advance their tools to the next level. Thus, many of the benchmarks require significant changes in some software packages if the developers hope to address those benchmarks.

Another goal of the working group is to inform researchers around the world, particularly those in academia, about the state of the art in distribution system analysis. Based on technical papers received for review, many in the academic community are under the impression that the state of the art in distribution system analysis is as it was in the 1970s. Part of this misconception is due to the paucity of technical literature on distribution system analysis. Although vendors of commercial distribution system analysis software have advanced the state of the art several-fold since the 1970s, they treat this information as proprietary due to the competitive nature of the business. Therefore, they typically do not publish the tricks of the trade that they have discovered unless they believe that they have a corner on their particular market. This is also a problem for utility engineers wishing to purchase software. It is difficult to discover the true capabilities of a tool until one has gained considerable experience using it.

The IEEE Distribution Test Feeders Working Group presented its roadmap for test feeder benchmarks at the IEEE PSCE 2009 conference in Seattle [6]. The test feeders are designed to motivate the distribution system analysis software community to implement the following modeling capabilities, which are seen as essential to developing tools that will support the SmartGrid of the future:

- High phase-order systems. Most tools now stop at three phases. Three-phase analysis is an improvement over the positive-sequence-only tools that were previously used. However, there are many places on the distribution system with multiple three-phase circuits sharing poles and neutral conductors. The ability to model this is key to locating some kinds of faults and dealing with such issues as stray voltage (neutral-to-earth voltage).
- Large distribution circuits. Modeling systems of 20,000 or more nodes is common now. In the near future, systems might require the solution of more than 100,000 nodes.
- Dynamics solution capability. This is needed for some DG screening applications. Dynamics analysis is essential for microgrid simulation.
- Simultaneous modeling of transmission and distribution. Eurocentric programs do this already because of a different definition of *distribution*. The value of many things done on the distribution system cannot be accurately determined without also modeling the transmission system.
- Modeling of large, meshed distribution networks. Although common in New York, Seattle, Chicago, and a few other cities, this might become essential if the future distribution system evolves into a looped form rather than the present radial form.
- Harmonics solution capability. This is important for evaluating stray voltages, the impact of blown capacitor fuses on railway signaling, the impact of increasing triplen harmonics–producing loads, and so on.
- Comprehensive modeling. Models for all types of devices that can exist on the distribution system. This is a never-ending task, but it takes a well-designed framework to allow expansion of the model library.

Some of these capabilities are already available in some tools. Many of the tools have powerful capabilities for the traditional analyses, but they lack the proper design to allow easy incorporation of new capabilities. One example of an area needing new capabilities is reliability analysis, which was described in the EPRI report *Guideline for Reliability Assessment and Reliability Planning—Evaluation of Tools for Reliability Planning* (1012450), which was published in 2006 [7]. Existing tools implement techniques that are at least 30 years old but are inadequate for the SmartGrid, for which distribution system analysis tools need to do more than compute annual average values.

Summary of Findings for Low-Voltage Urban Networks

In addition to EPRI's OpenDSS program, the project advisors identified 10 distribution system analysis programs that they either were using or would consider purchasing. A questionnaire was sent to those vendors to identify their capabilities with respect to urban LV networks. Seven returned responses, and all seven claimed to have the capability to model and analyze highly meshed networks such as those found in urban LV networks.

This result is surprising. The research team was aware of only three that had some form of meshed network capabilities before the survey. This result indicates that the vendors have been responding to demands by users to include network analysis for either spot networks or large urban networks.

One of the issues that arises with a project of this nature is that of vaporware. That is, vendors can claim to have capability that they do not, hoping that they will be able to develop it before they have to deliver it. This is a global problem with all types of software. With respect to the main subject of this report, good sparse matrix tools are now readily available. Vendors who do not have urban network solution capability can add it within a matter of weeks, or even a few days, if they have a particularly capable software development staff. At least one vendor who responded to the survey is suspected to have implemented the capability after receiving the questionnaire. EPRI has received conflicting information on another analysis tool whose vendor responded in October 2009 that it could handle highly meshed networks. However, in March 2009, a conversation with a developer for the vendor revealed that the tool had weakly meshed network capability but could not yet handle networks of the type found in highly meshed urban LV networks. Did the vendor develop the capability between March and October, or does the vendor hope to develop it before is actually has to produce results? Vendors are given the benefit of the doubt in this report and taken at their word. However, distribution engineers purchasing distribution system analysis tools for urban LV networks would be prudent to investigate all claims carefully.

The other perspective on this topic is that if a distribution engineer were to find a package with desirable features that lacks a good way of handling urban LV networks, it is good to know that the capability can be added relatively quickly. Often, when a new distribution system analysis package is purchased, it takes one or two years before the package is fully integrated with company data sources. A vendor with good power system analysis knowledge and software expertise should be able to implement the capability within that time frame. The knowledge of how to do full three-phase or higher analysis of highly meshed networks is becoming increasingly common. One reason that EPRI released the OpenDSS program as open source is to show analysts one way that this can be done.

A summary of individual tools follows. The OpenDSS is described first, to serve as a reference case for the others.

Open Distribution System Simulator (OpenDSS)

The Open Distribution System Simulator (OpenDSS) program description is provided as an example of a distribution system analysis program with advanced capabilities. The intent is not necessarily to promote it as an alternative to commercially available tools but for it to serve as a well-established reference against which to compare other tools.

The initial development on this program was begun by Electrotek Concepts, Inc., in 1997. The program was acquired by EPRI in 2004. The initial goal for the program was to provide a tool that was able to analyze nearly all the frequency-domain analysis issues that might be encountered when DG is connected to the distribution system, including annual value of service computations, harmonics analysis, dynamics analysis, and power flow.

Although commercialization of the program was briefly considered, it has been used primarily as a research platform and to support internal consulting work. In mid-2008, EPRI decided to make its Distribution System Simulator (DSS) program open source in order to cooperate with other open source projects in the advancement of grid modernization, or SmartGrid, efforts. Thus, the name was changed to *OpenDSS*.

In contrast to the other distribution system analysis programs included in this survey, OpenDSS was not originally developed as a power flow tool. It has evolved from harmonics analysis tools, which naturally gives it some unique capabilities in this class of computer programs. For example, harmonics analysis of utility systems from the loads up to and including the transmission system requires the capability to model distribution systems and transmission systems in arbitrary detail and phase order. This obviously would include meshed networks such as urban LV networks.

The ancestry of the power flow methods used in the program dates back to the early 1980s and the systems engineering department of McGraw-Edison Power Systems. In searching for a better way to initialize the harmonic current sources, researchers observed that a simple modification to the harmonic analysis algorithm would successfully solve multiphase power flows on complicated distribution systems, either radial or meshed. A slightly modified form of the algorithm was implemented into the OpenDSS program and has proven quite successful in solving power flows in highly complex circuit configurations, including urban LV networks. In recent years, the program as been used extensively for stray voltage, or *neutral-to-earth voltage* analysis, which arguably requires the most complicated models encountered in distribution analysis [8]. One reason for making the program open source was to show others in the industry how to construct complex circuit models and solve these types of problems, regardless of whether they would use OpenDSS. This is viewed as being one of the more efficient ways of encouraging the industry to adopt better modeling techniques that will be required to support distribution system analysis in EPRI's vision of the future modern grid.

Several features in the software design of OpenDSS differ from the typical distribution system analysis program. These features often seem a bit unusual to power engineers who are accustomed to more traditional ways of doing things, but they enable the extraordinary flexibility found in the program.

For example, the majority of power system analysis programs are based on the traditional power flow model—a bus has a load. Some programs allow only one type of load at a bus. Most of the other programs described here break the load into three categories: constant P and Q, constant Z, and constant current—the so-called "ZIP" model. In contrast, the OpenDSS was designed with the concept that a load has a bus. This might seem like a subtle semantic difference, but it enables extraordinary load modeling capability. There can be any number of loads at a bus, each with its own characteristics. The OpenDSS currently allows several different load models, with the prospect of adding more. Each load can have its own load shape and growth pattern. In discussions at power industry meetings, some analysts have indicated that this would cause their power flow algorithms to fail to converge. However, EPRI's experience is that it generally works well with the OpenDSS algorithm. The Brazilian TCIM program can do something similar [5]. The Battelle Pacific Northwest National Laboratory (PNL) GridLab-D program might also have a similar concept, because it can aggregate the load from all appliances in a house up to the common bus. The vendors who responded that their network solution algorithm uses a CI method are probably doing something similar, although sometimes they model the injection as a bus quantity rather than a load quantity.

There are other areas in which the OpenDSS does things differently. It was designed from the outset to be able to perform annual simulations, which also gives it the ability, for example, to perform daily simulations of wind plants at one-second intervals. In contrast, most other programs in this survey were originally designed to solve one power flow, typically at peak demand. This is good for some types of distribution planning, but it does not expose the true time- and location-dependent value of DG, plug-in hybrid electric vehicles, conservation voltage reduction (CVR), storage, and other methods of active control of the distribution system. One can often get a misleading answer for these and other SmartGrid issues if the program can perform only a single snapshot power flow.

EPRI has been preaching this message for several years, and several vendors are now providing some form of this capability, even if only to perform a single-day simulation. This is evident in some of the responses but notably missing in others.

The OpenDSS is provided primarily as an electric circuit solution engine with a rudimentary user interface to help users develop the scripts that drive the program. All the circuit description information is contained in the scripts; no database is provided. Thus, it is more suitable for the research and consulting environment than the utility engineering and planning user environment that requires a data management system. However, users are free to develop their own interfaces and data management systems, if they have the capability. Currently, some university researchers claim to be doing this. A COM interface to the program is provided in order to allow the OpenDSS to be driven by a user-written program in the Microsoft Windows operating system environment.

CYMDIST

The CYMDIST program was developed by CYME International in Montreal, Canada, which was acquired in December 2008 by Cooper Power Systems. This program might have the largest number of users around the world of any of the programs mentioned here. Over 5000 copies worldwide in over 100 countries are claimed.

CYMDIST uses a fairly generic three-phase system model that runs from a Microsoft Access database. EPRI has licenses to use this program and has a couple of different converters from one of the export formats to the OpenDSS program. This program has some powerful features and yet some that could be improved.

The program has a three-phase model, but it appears to have only a balanced symmetrical component line model. When it computes the impedances from the geometry, it appears to compute only the positive- and zero-sequence impedances. That is not apparent from the marketing literature, but the EPRI team has surmised it from the data sets that have been converted for the Green Circuits project. Although this model is good for many analyses, not being able to truly represent line unbalances makes it difficult to solve the IEEE test feeders. The research team is not aware of the vendor publishing test feeder results or making claims that it can solve the test feeders. However, CYME personnel have begun to participate in the IEEE PES Test Feeder Working Group.

The program has improved ability to handle load shapes in the last few versions, but it has room for improvement. It does not appear to have a good mechanism for supporting sequential simulations.

Nevertheless, CYME has made good efforts to add new features such as supporting DG analysis with what appear to be good models of machines. A dynamics simulation was demonstrated at the 2008 IEEE Transmission and Distribution conference. It is not known whether this capability made it into a release.

A COM interface module can be purchased separately to allow computer-savvy users to drive the program from some other program. Many of the interfaces seem to be devoted to accessing the database, which can also be done through Microsoft Access.

The vendor has a strong business helping its users connect the program to their GIS systems and other databases that contain regulator settings, for example. Before 2009, the only Common Information Model (CIM) interface to a distribution system analysis program in North America was written for this program. However, this fact is a bit misleading, because only the line connectivity data were imported from the CIM database. The CYMDIST equipment database is still a better a repository for complex device settings than CIM is.

The response to the urban LV network questionnaire was weak. The vendor simply submitted information that can be found on-line in their marketing literature. The vendor markets an add-on module to the basic package, specifically for “secondary networks.” The literature contains little information about the capabilities of the add-on module. It apparently uses the graphical editor in the main package, but the literature does not indicate whether the data are connected to the main radial system solver.

It is not known whether the radial system solver can solve weakly meshed systems, although it does appear to handle closed switches between feeders in some manner. A potential user should attempt to get more detailed explanations of the capability before purchasing.

SynerGEE Electric

SynerGEE Electric (formerly known as Advantica, and before that, as Stoner) was acquired by German Lloyd (GL), and the vendor web site is now www.germanlloyd.org. The vendor did not respond to the questionnaire. However, this package has been available for many years, and EPRI personnel are familiar with the principal designers of the package. EPRI has held licenses to the package at various times, and SynerGEE Electric developers have cooperated in the conversion of data sets over the years. Several data sets for this program were converted to OpenDSS format for the Green Circuits program.

This program has a three-phase distribution system model. It is not known whether a higher phase order model can be developed. The vendor is known to claim the ability to model meshed networks and annual load shapes, although evidence of this has not been observed firsthand. In fact, SynerGEE Electric might have been one of the first of the main distribution analysis vendors based in the United States to offer this capability.

The extent of the capability for modeling unbalances is not known. However, the chief architect of the package is well known in the industry to have the knowledge to do all the types of analysis of interest to this project.

This vendor has been reluctant to publish its results for the IEEE PES test feeders. Working group members have often found that this is a sign that a vendor cannot handle the unbalances in the test feeders. This should not be the case with SynerGEE Electric, and for the moment, it is assumed that the vendor simply wishes to protect knowledge of its capabilities from its principal competitors.

The vendor also claims to have models for DG, and there are indeed entries for generators in the program's database. Seamless integration with ESRI's ArcGIS is also claimed. Of course, EPRI has learned through its experience in the Green Circuits project that no two GIS implementations are alike when it comes to distribution system analysis models. Each must be painstakingly converted on its own.

The main database is Microsoft Access, and it is therefore compatible with most of the Microsoft Office products. The vendor provides a COM interface version that users can use to access the data and functions of the package from user-written programs. Many of the COM functions appear to mirror the database structure. The database structure is relatively simple and straightforward.

EPRI has converted several SynerGEE Electric feeder models to OpenDSS scripts, using a semiautomatic process based on MS Access queries and VBA code. This is one of the more straightforward conversions that researchers have encountered.

Windmil

Milsoft has the bulk of the rural electric cooperative market in the United States with its WindMil distribution analysis tool. Milsoft provided a Microsoft Windows-based interface early on, and the company has been quite responsive to the needs of its user base ever since. Although its features favor the rural electric cooperative planning practices, it is a powerful package that should work for most urban utilities as well.

Milsoft dramatically increased its footprint in its market when it acquired the Porche Systems outage management system. It was able to merge it with the Windmil tool and implement it for a price considerably lower than that of its competition. This put it within reach of the rural electric cooperative utilities, many of whom are often more willing to try new technologies than large utilities are.

Milsoft frequently has the largest booth at power industry trade shows of any of distribution system analysis vendors based in North America. This promotes an image that they are quite profitable, and as of this writing, it is likely true. In recent years, Telvent DMS has begun to compete on booth size. Such measures are not always reliable, but they could well be an indication of the direction the industry is going.

The Windmil package is also used by a few investor-owned utilities. However, the features and data models of the program are more desirable to rural utilities than to urban ones. Milsoft goes to great lengths to satisfy the rural market and keep its customers happy. Milsoft sponsors many rural electric events, and its employees are active participants in these events. It seems to have a happy user base.

The package is based largely on a radial system power flow solver. From some of the claimed analysis functions, it must at least be able to solve weakly meshed networks. Milsoft responded to the questionnaire on this project that Windmil can solve "looped networks" for power flow, short circuit, and other functions. Because Bill Kersting serves as a consultant to Milsoft, the power flow method is very likely a close relative of his method, which would be classified as a weakly meshed method [2].

The Windmil model is a full three-phase model. The electrical engineering data model was the inspiration for the National Rural Electric Cooperative Association's Multispeak model (http://www.multispeak.org). The highest phase order it can handle appears to be three.

It is not entirely clear how unbalanced lines are modeled. Symmetrical component data can be entered, but it is not known whether one can enter arbitrary impedance matrices. However, line geometries can be entered from which the program computes line impedances. Therefore, it is likely that the Windmil program can compute unbalanced impedance matrices. This capability is claimed in the Milsoft response. If it is indeed a full implementation of Kersting's method, unbalanced line modeling should be included [2]. Milsoft is one of the few vendors that has cooperated fully in the development of the IEEE PES test feeders and has demonstrated that the Windmil program can accurately solve some of them. It could not solve these unless it had the ability to solve unbalanced line models. There is currently no IEEE test benchmark to verify that a program can solve a urban LV network, so this question remains open.

Milsoft has expressed an interest in interfacing to the OpenDSS for the purpose of acquiring harmonics analysis capability. If they follow through with this, they could also use OpenDSS for urban LV network analysis. EPRI has converted Windmil databases to OpenDSS for use in the Green Circuits analysis. The conversion is relatively straightforward. The Milsoft response indicates that, after January 2010, the database will be open through SQL. It is uncertain what this means; the existing database is not a closed database.

DEW

The Distribution Engineering Workstation (DEW) was originally developed with EPRI funding beginning in the 1980s. The program is now maintained entirely by EDD, an offshoot of Virginia Tech. Recently, the program itself (binary executable) can be obtained from EDD at no cost. However, most users contract with EDD for support. The DEW appears to be customized for each client.

The vendor boasts the capability to solve large circuits with arbitrary unbalance (see Appendix E). Lines cam be described by impedance matrices, which lends credibility to the claim of true unbalanced modeling. The vendor also claims the ability to solve closed loop networks. A tree and cotree technique is used to solve meshed networks. A recent paper referenced in the response describes a method for establishing the optimal tree. Therefore, the network solution algorithm has probably evolved from a radial circuit solver.

For urban networks, the program appears to solve the primary system and the secondary system separately. This is done with a special dynamic link library (DLL) add-on to the program. The primary system is solved first, and the power flow results at the transition points serve as inputs to the secondary system.

The program appears to be limited to three phases, based on the variables available for display on the circuit diagram. However, some internal data structures seem to be sized for six phases, so the true limit is unclear. Only one-, two-, and three-phase systems are mentioned in the response.

The DEW data structures and the interactive user interface were innovative for the time that development started, but they appear dated now. There is an emphasis on functionality of the algorithms, but less attention is given to providing an intuitive user interface.

The DEW does not have a COM interface for custom applications. If users want to customize the DEW, an application programming interface (API) can be licensed that allows computer-savvy users to write add-on DLLs in C++. However, one choosing to go this route must be prepared to rely on EDD for support and must have sufficient programming expertise on staff. This skill set is lacking in most utilities.

Telvent DMS

The analysis software in the Telvent DMS package was originally developed by DMS Group Ltd, Novi Sad, Serbia. It appears to date from the early 1990s, although it possibly existed before then. Based on the advertised capabilities, the package might presently have more functionality than any of the other packages considered here. The list of power flow and other planning functions during demonstrations of the software goes off the screen. The vendor's response shows a list of 41 functions. Of course, it is likely that some of these functions must be licensed individually, and it should not be expected that all will be present in a given installation.

The package is an offshoot of University of Novi Sad (Novi Sad Innovation Center). Telvent DMS Group claims to be an information technology company. Early in 2009, its web site boasted that it had over 300 developers, including 40 with PhDs, working on the program. The company's response to this project's questionnaire states that over 500 "outstanding experienced power and software engineers" are involved in the development of the system. That would indeed make it the largest company in the distribution system analysis market. If this number of developers is not exaggerated, it will be difficult for competitors to keep up.

A certain percentage of these developers are likely graduate students at the university. This arrangement often spells trouble for a commercial product, leading to kludgy user interfaces and unreliable software. However, the demonstrations appear to be robust. At trade shows, the company typically demonstrates simulations of the cities of Milano or Belgrade, for both of which they claim to have the entire primary and secondary distribution systems completely modeled.

The vendor's main business is in the support of distribution management systems (hence the DMS acronym in the name). Each system is customized for the client, which would indeed require a large staff to maintain. In contrast, most other vendors listed here release a version of their software, and the user is more responsible for customizations. One thing this might mean for the user is that the user can expect to rely more on the vendor for building and maintaining system models than it might be accustomed to doing with other packages.

The package seems to perform well on both radial and looped systems. The solution time seems remarkably short for the size of problem claimed. The loop flow after closing a switch is readily displayed. Of course, this could be done with a weakly meshed solution algorithm. Neither the vendor's marketing literature nor the response to the questionnaire in this project reveals many details of the solution technique.

Telvent DMS has apparently closed on its first major sale to a United States utility in 2009. Also, at least one utility in Canada is using the package to implement a volt/VAR control (VVC) scheme. The package is certainly one of the more complete and capable packages available. Its market might be considered to be more the distribution management systems market (complete operational systems) than the distribution planning market. However, EPRI expects those markets to merge in the future and blur the lines between them. Like other vendors entering the market later, Telvent DMS appears to have leapfrogged the competition in many areas by not having the inertia of an installed base and likely having access to a low-cost software developer pool.

Some of the information concerning this product received from third-party sources (interviews with users and competitors) raises some questions that potential purchasers should explore further with the vendor. Although the program gives a quick solution to the loop flow problem after closing a switch, one user and one competitor cast doubt on its ability to solve highly meshed urban LV networks such as those found in Seattle, New York, and Chicago. However, with the large software development staff and the ready availability of the techniques, it is likely that the vendor could implement this capability. When questioned in early 2009, a representative of the vendor confidently proclaimed that they could solve that problem if asked to do so. The vendor's response to the questionnaire is somewhat ambiguous, so it is not known exactly what capability the vendor actually has.

A competitor in the distribution management system market downplayed the claim of 40 PhD holders supporting the programs. He said simply that "their PhD is not the same as a United States PhD." Nevertheless, EPRI has found the vendor's representatives at trade shows to be competent.

Telvent DMS claims interfaces to the CIM and to Multispeak. These claims have not been independently confirmed as of this writing. The vendor did not participate in the CIM interoperability tests in December 2009. No information on their participation with Multispeak is available.

ASPEN Distriview

Distriview is a distribution system analysis program provided by a reputable vendor, Advanced Systems for Power Engineering, Inc. (ASPEN). ASPEN is probably better known for One-Liner, its short circuit analysis tool for transmission.

The software appears to use modern solution techniques. The response does not provide a great deal of detail, but it would not be surprising to find that the program uses a power flow method of the same class as OpenDSS. It solves meshed networks in actual values in the phase domain. Any transformer connections can be modeled, and any number of voltage levels can be modeled. In addition to the usual power flow and short circuit calculations, it can perform harmonic flow analysis. Given the heritage of the vendor in short circuit analysis, this program could very well have the capability of a good meshed network solver.

The program has machine models in the power flow. This could be an advantage over some of its competition. Despite this fact, there is no dynamics capability. This would seem to be an incremental addition to the program if the program's users were to request it.

Loads can be arbitrarily connected. They can be of the typical ZIP form (constant Z, constant I, constant kVA). There are no capabilities for load shapes, which implies there are no capabilities for daily or annual simulations.

The vendor's response indicates that the program is limited to 32,000 nodes. It is not certain why there is such a limitation, given that dynamic memory allocation is a natural part of all programming languages. Most distribution system analysis tools do not have a limit, unless the vendor chooses to license different sizes for commercial purposes. This size is large enough for most distribution system analyses being performed today, but some urban LV networks would take this to the limit in a full three-phase model. This size would likely have to be increased for future needs.

The program uses a combination of text files and binary files for storing its circuit model. The vendor claims a Multispeak interface.

Paladin DesignBase 2.0

The vendor of Paladin DesignBase, EDSA, did not respond to the questionnaire. EPRI has seen demonstrations of the software, which appears to have quite advanced real-time operations capability for distribution systems. The main market appears to be industrial and government sites, which tend to have radial systems. The web site discusses capabilities that would appear to require some network solution capability, but the material is ambiguous. Urban LV networks were not mentioned.

Etap

The etap vendor, Operation Technology, Inc., did not respond to the questionnaire. The website information is ambiguous with respect to capabilities for solving urban LV networks.

EasyPower V9.0 for Windows

The vendor begins its response with a claim that the program has the fastest processing speeds on the market. This is a bold claim, and one wonders how it was determined. It is marketing hype, or is there real evidence? A good test benchmark is needed to settle such claims.

The present version of the power flow software provides only balanced solutions. It is assumed that this means it has only a positive-sequence model of the system. A multiphase, unbalanced version is promised for 2010. This vendor is in the process of rapidly expanding the capabilities of its offerings to keep up with the competition.

The vendor attributes the program's speedy performance to Tinney's sparse matrix algorithms [9]. This method can solve highly meshed networks. The solution method is called the *CI power flow* method. Harmonics and dynamic stability solution capabilities are also claimed. Given this information, the solution methods are likely of the same class as those of the OpenDSS, although perhaps limited to positive-sequence models at present.

The program has the standard constant kVA, constant Z, and constant I load models. In addition, a fourth option is provided for modeling motors. No mention in the program is made of load shape capability. However, the vendor indicates that the program is used in real time applications, presumably some sort of distribution management system.

Dapper

The Dapper program is provided by SKM Power Tools. The information about this vendor did not come directly from the vendor but from a user. The user has been using the program to solve a downtown network in Cincinnati for a number of years. The data for the network are maintained separately from the other distribution system analysis tools.

Also, EPRI's system studies group has had experience using this program, but the group was unaware of its ability to solve urban networks. The group had converted a model to OpenDSS because Dapper used a symmetrical component line model that was unable to represent the unbalance in the distribution lines that severely limited a heavily loaded feeder. Thus, it was assumed that the power flow was performed for the positive sequence only; that might be a limitation of the program.

There might be conflicting information on the method that the program uses for network solution. From the Dapper user manual, it appears to be a weakly meshed radial solver, whereas from the website, it appears to be a somewhat standard, sparse nodal Y matrix approach, perhaps similar to that described for the OpenDSS. On the power flow setup menu, the user has two choices for solution: (1) current injection with a kVA mismatch target or (2) a Newton method with a voltage convergence criterion. It is not certain which would be better for networks.

Other Tools

The following is a summary of other tools with which EPRI is familiar, but which were not included in the polling. These were either considered to be transmission system tools or were simply not identified by the project advisors as a program of interest. These summaries are included for informational purposes only and are not to be construed as complete and comprehensive. Readers should contact the vendors for more information.

GridLab-D

This is an experimental test bed being developed by the Battelle Pacific Northwest National Laboratory (PNL) to study the impact of policy changes on energy use patterns. It is an open source C++ computer program that can be found at http://sourceforge.net, the same web site where OpenDSS can be found. In fact, the GridLab-D project was partly responsible for inspiring EPRI to make OpenDSS open source.

The system is designed to model the power grid from the customer appliance up to the generation station. It basically models individual loads stochastically. This is an enormous model and would be implemented on massively parallel computers that reside in the laboratory.

As of May 2009, GridLab-D did not have significant capabilities for LV urban networks. Distribution systems were modeled using the ladder approach described by Kersting [2]. This is a three-phase model. Transmission systems were modeled using a relatively simple Gauss-Seidel positive-sequence power flow such as those built in the early 1970s [4]. This might seem old-fashioned—and it has its problems—but it is naturally amenable to parallel processing, which is a main concern of PNL.

This latest information on this program is that a solution method based on the TCIM method developed by the Brazilians is being implemented [5]. If this is true, it would give GridLab-D the capability to model LV urban networks.

PSS/E

PSS/E is a popular, comprehensive transmission system analysis program that is marketed and supported by Siemens PTI. This is possibly the most common program in use for this purpose in the world. It is nearly the de facto standard in many areas, including the eastern interconnect region of the United States.

Utilities that already have this program for transmission system analysis might have a tendency to use it for studying LV urban networks because they already have user expertise on staff. However, at other utilities, this capability is not easily accessible to distribution engineers. When used for power flow studies, the model is balanced positive sequence. The short circuit module would be able to model ground faults by adding the zero-sequence impedance.

PSLF

The acronym *PSLF stands for positive sequence load flow*, which describes the basic purpose and modeling capabilities of the program. The vendor is GE Power Systems. This program is the standard for the western interconnect region of the United States.

When used to model LV urban networks, the system model would be balanced positive sequence. The short circuit module would be able to model ground faults by adding the zero-sequence impedance.

T2000

Transmission 2000 (T2000) is a transmission system analysis package marketed by Commonwealth Associates. It has a full slate of transmission system analysis functions. Although it certainly has mesh network analysis capabilities, there is no indication in any of its literature that it has the ability for detailed three-phase modeling expected in distribution analysis.

When used to model LV urban networks, the system model would be balanced positive sequence. The short circuit module would be able to model ground faults by adding the zero-sequence impedance.

ASPEN Power Flow

The ASPEN Power Flow software is a transmission-oriented power flow that accompanies the popular One-Liner protection program marketed by ASPEN. Although ASPEN's DistriView software has three-phase modeling capability, there is no indication on the company's website that the Power Flow product also has this capability. Therefore, one might assume that if it were used to model LV urban networks, the system model would be balanced positive sequence. The One-Liner program would be able to model most fault conditions on urban networks by adding the zero-sequence impedance.

NEPLAN

NEPLAN is offered by BCP Switzerland (http://www.neplan.com). The website claims more than 3000 licenses have been issued to more than 800 companies. This would probably make it the second-most-used distribution analysis program—if one can call it that—in the world, after CYMDIST. Despite this, there does not appear to be a licensee in the United States. It is uncertain whether there are any in Canada. If there is a reason other than high cost, it is probably because the system model does not follow the North American model.

NEPLAN claims to be the most complete power system planning tool with the most friendly user interface of any of its competitors. Its literature claims a number of "mosts" for its features. NEPLAN representatives are quite proud of the dynamics simulation capability. This might be mostly marketing hype, but it certainly seems to be a powerful package, and the hype might well be justified. The dynamic simulation capability—which would set it apart from most other tools mentioned here, except for the DIgSILENT program—is used primarily for wind generation studies. It also has an electromagnetic transients capability, which is unusual for distribution packages.

At the IEEE PSCE 2009 conference, the vendor indicated that PSS/E was its main competition. Thus, the vendor appears to position this program as a transmission system analysis program, although it has significant distribution system analysis capabilities. One major disadvantage that NEPLAN has in the distribution analysis market in the United States is initial cost.

The marketing literature emphasizes wind plant simulation, reliability-centered maintenance, and risk based planning. There is an emphasis on economics in the planning area. The model is definitely Euro-centric, as one might expect given the location of the company. The European distribution system model includes a portion of the transmission system as well as the MV distribution system. Thus, the model differs from most North American offerings.

The program can perform harmonic frequency scans and compute estimates of root-mean-square harmonic distortion according to the International Electrotechnical Commission (IEC) standard IEC 1000-2-6. This capability suggests it might have at least one solution engine similar to the OpenDSS. The literature suggests that there are several solution engines working from a common database. Having dynamics analysis capabilities would also suggest a similar solution engine, although it is unclear whether the dynamics analysis is full three-phase. Many computer programs with dynamics capability resort to positive-sequence models. There is no evidence that NEPLAN can handle higher order systems than three-phase systems, although it might.

The vendor offers a standard C language API toolbox, so the assumption is that the main method of customizing the code is by writing a DLL in C or C++. This toolbox is advertised as “for research,” so it is probably difficult for most utilities to use. NEPLAN also advertises compatibility with MATLAB and SimuLink. Interactivity with other packages is through SQL and ASCII export files.

Because the program can model the transmission system, it seems likely that it can also solve urban LV networks. Potential North American utility users should prepare for a different kind of tool than they are accustomed to. However, it would not be surprising if tools of the future adopt many of the features found in this package.

DIgSILENT PowerFactory

This is a powerful electric power system simulation program provided by DIgSILENT GmbH of Gomaringen, Germany, with power flow, dynamics, and electromagnetic transients simulation capabilities.

The EPRI PDU System Studies group has used this program for transmission studies. It has been used for distribution system analysis with mixed experiences. It has network solution capability and should be capable of solving large urban LV networks, but it might appear to be overkill for most distribution planning problems. Distribution engineers report finding it difficult to use. Consultants and researchers who have to adapt to new and unusual problems would have better appreciation of its features.

The program has a scripting language that can be used for customizations. It has found a market in North America as well as around the world with its ability to model wind generation.

4 ANALYSIS TOOLS MATRIX (FOR URBAN NETWORKS)

Distribution System Analysis Programs

Table 4-1 summarizes the essential capabilities of the programs included in the survey. Each tool included in this table would be considered a distribution system analysis tool, as opposed to a transmission system analysis tool, although some of the tools might also have some capabilities for transmissions system analysis.

Table 4-1
Distribution system analysis tools matrix

Program	Vendor	Radial	Network	Three-Phase	Comment
OpenDSS	EPRI	Yes	Yes	Yes, *n*-phase	Now open source; available at no cost.
CYMDIST	CYME/ Cooper Power	Yes	Yes	Yes	Quite popular distribution system analysis tool. Web site claims network solution example, but have heard conflicting stories on capabilities.
SynerGEE Electric	Advantica/ German Lloyd	Yes	Claimed but not verified	Yes	Have claimed network solution capability for years, but examples are sparse.
Windmil	Milsoft	Yes	Yes	Yes	Has the lion's share of the rural utility market. Present network capability is probably an extension of the ladder network technique. Looking at interfacing to OpenDSS.
DEW	EDD	Yes	Yes	Yes	The program (binary version) is available at no cost. Support and developer's kit must be contracted. Tree/cotree solution method. Has demonstrated solution of large networks.
DMS	Telvent DMS, LLC	Yes	Yes	Yes	Geared toward large distribution management systems market. Seems to have at least weakly meshed solution capability. Capability for LV urban networks is unknown, but could be implemented by now. Large support staff.

(Continued)

Table 4-1 (Continued)
Distribution system analysis tools matrix

Program	Vendor	Radial	Network	Three-Phase	Comment
ASPEN Distriview	ASPEN	Yes	Yes	Yes	Has protective device simulations.
Paladin DesignBase 2.0	EDSA Micro	Yes	Some capability likely	Yes	Strong in industrial and government market. Has some capabilities that would suggest network solution capability, but specifications are not known. Web site is ambiguous on the ability to model unbalanced networks.
etap	Operation Technology, Inc.	Yes	At least positive sequence	Unknown	Boasts real-time system support and interfaces to SimuLink. Website is ambiguous on ability to model unbalanced networks.
EasyPower	ESA	Yes	Yes, positive sequence	Yes, except network power flow	Advertises that it is a simple distribution power flow. Meshed network capability appears to be positive sequence only for now. Full three-phase promised.
Dapper	SKM Power Tools	Yes	Yes	Limited to symmetrical component	Three-phase modeling claimed, but actual usage experience indicates a symmetrical component model.

Other Tools

Table 4-2 compares other tools that have been considered for modeling and analysis of urban LV networks. These are primarily transmission system analysis tools that can generally solve meshed networks with little difficulty. However, either they do not have features that are commonly associated with distribution system analysis or they have advanced features that are not generally needed for distribution system analysis.

Table 4-2
Analysis tools matrix for other programs

Program	Vendor	Radial	Network	3-Phase	Comment
PSS/E	Siemens PTI	Yes	Yes	No	Transmission power flow; positive sequence only
PSLF	GE Power Systems	Yes	Yes	No	PSLF stands for *positive sequence load flow*
T2000	Common-wealth Associates	Yes	Yes	No	Transmission power flow; positive sequence
ASPEN Power Flow	ASPEN	Yes	Yes	No	Transmission power flow
NEPLAN	BCP Switzerland	Yes	Yes	Unknown but likely	Strong emphasis on dynamics and wind power, subtransmission and distribution
DIgSILENT PowerFactory	DIgSILENT GmbH	Yes	Yes	Yes	Includes electromagnetic transients and dynamics

5 EXAMPLES

During this project, EPRI was simultaneously working on two urban network systems for other reasons. One network was submitted by Nashville Electric Service (NES) for the plug-in hybrid electric vehicle impacts project. This project uses the OpenDSS program. The other was a much larger network in Manhattan, which was modeled by EDD using their DEW program. A brief summary of some of the experiences is provided in this section.

EPRI assisted NES in constructing the model of their network. NES hosted a regional OpenDSS training for themselves and several other users from universities, consulting companies, and other utilities. Then they set about gathering data for the model. The data were compiled in an Excel workbook and then converted to OpenDSS text scripts. A summary of the circuit with the loading data known as of the writing of this report is shown in Table 5-1. This model is relatively lightly loaded compared to the capacity of the system, and the OpenDSS solves this model easily.

Table 5-1
Nashville Electric Service network circuit summary

Parameter	Value
Devices	1147
Buses	281
Nodes	843
Total Iterations	3
Control Iterations	1
Maximum Solution Iterations	3
Maximum Per-Unit Voltage	1
Minimum Per-Unit Voltage	0.90002
Total Active Power	9.17202 MW
Total Reactive Power	3.86004 Mvar
Total Active Losses	0.0880656 MW (0.9602%)
Total Reactive Losses	0.26984 Mvar

One of the problems encountered was in moving the data from Excel to text files. Tab characters and extra blanks were introduced into line and bus names, which resulted in elements not being connected. Such textual problems are frequently encountered when converting from database forms to text forms, and personnel who are performing this task must understand what the various software tools are doing to text (some insert extra nonprinting characters) and must pay diligent attention.

Another problem that will likely be an issue for utilities having two different kinds of LV networks with different voltage levels is that transformers and loads will be inadvertently connected to the wrong network in the model. The NES circuit had both 480 V and 216 V LV networks. When the model was first constructed, a 480 V transformer was inadvertently connected to the 216 V network. In a typical power flow program, the power flow solution will fail to converge because the voltages are too far from normal. The OpenDSS managed to converge to an answer because of its special treatment of load models, but there were high currents all over the network and no clear indication of where the fault was. In a radial circuit, the fault location would be more obvious and easier to isolate. It took some tedious, systematic sleuthing to find the misconnection. This is likely to be a common experience for utilities just beginning to gain experience building networked models, and good diagnostics for debugging models would be a highly desirable feature of tools for urban network analysis.

Another challenge of handling urban LV networks is displaying the circuit drawings in a meaningful manner. In the NES case, the OpenDSS solves the primary and secondary simultaneously as one circuit. Therefore, its default behavior is to show both circuits on the same diagram. As is frequently the case for urban LV networks, the primary and secondary are essentially on top of each other. The solution for the NES circuit was to translate the secondary horizontally to the right so that the transformers connecting the two networks end up in the middle of the diagram. This is the diagram shown in Figure 5-1.

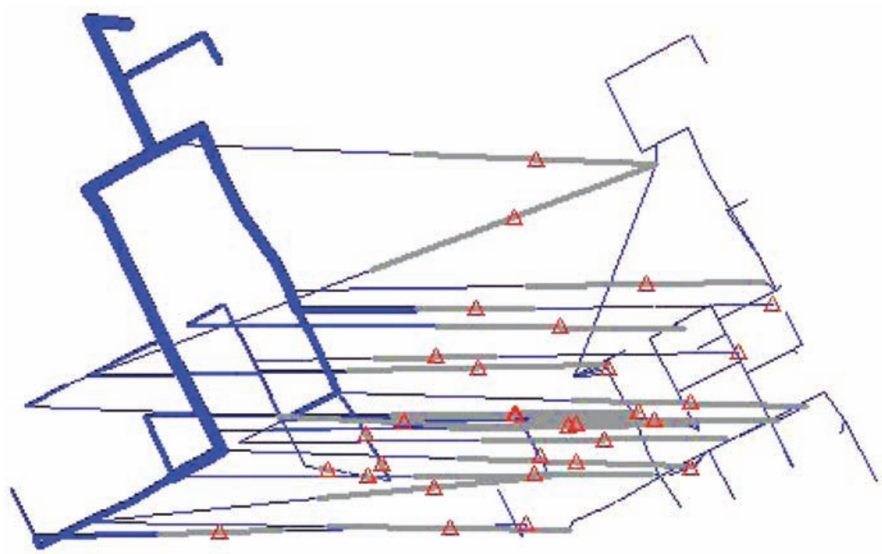


Figure 5-1
Nashville Electric Service circuit model display from the OpenDSS

Another solution to the overlapping graphics problem is that of the EDD DEW program (see Figures 2 and 3 in Appendix E). This is a model of a Con Edison network. The DEW solves the primary circuits and secondary circuits separately, in that order. The sequence of the solution process is recorded on the processing status window in the dialog form shown in Figure 5-2. Data entry and maintenance is performed by user interaction with the circuit diagram. It is an advantage for this approach to keep the primary and secondary networks segregated. In contrast, the OpenDSS uses the circuit diagram only to display results; all data entry and maintenance is performed with the script files.

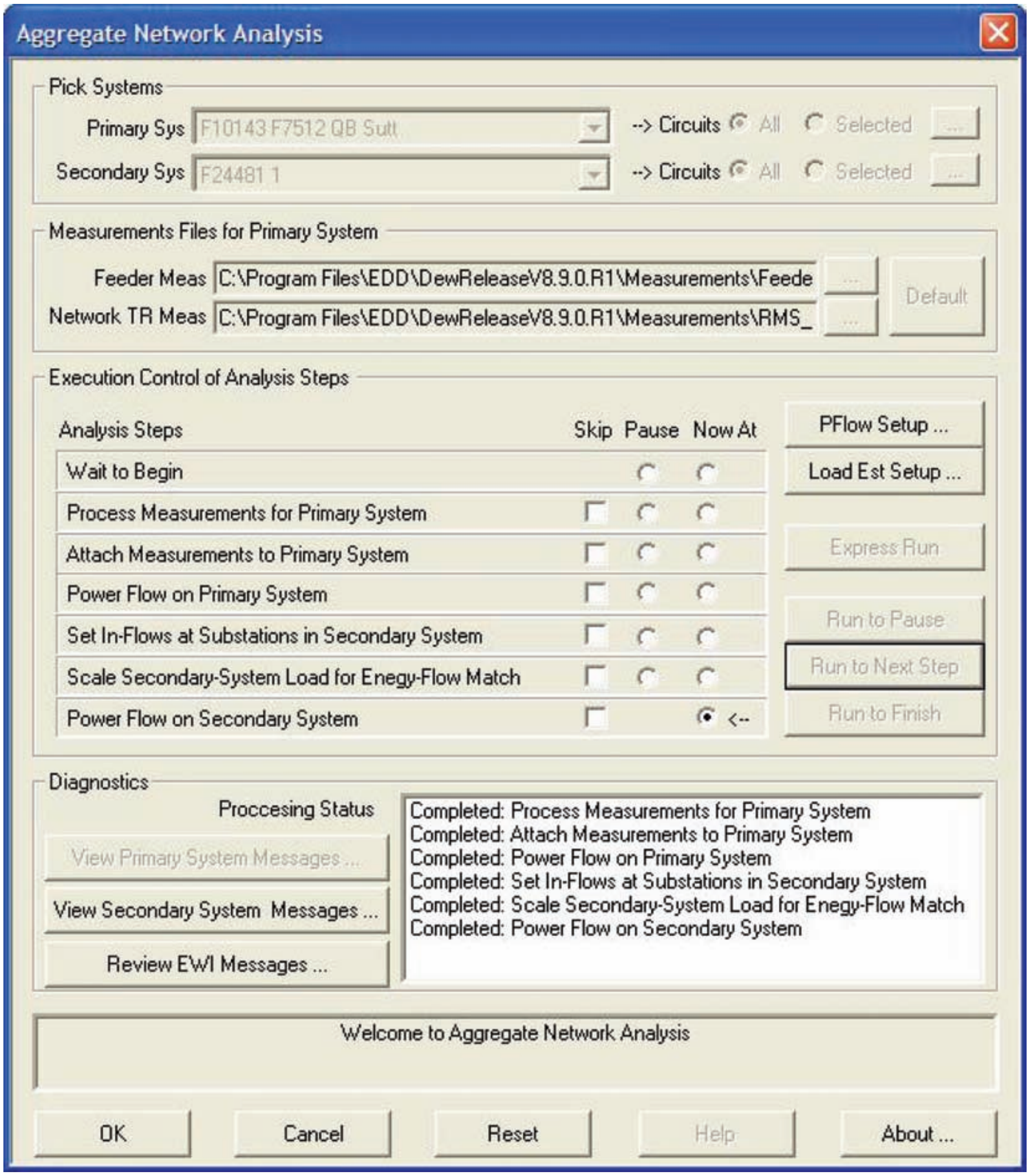


Figure 5-2
Report showing the DEW aggregate network analysis process

The DEW uses a loop solution method for solving networks. There are more than 900 loops in this circuit. The complete solution process takes approximately 30 seconds on a Lenovo T61 laptop computer.

The aggregate network analysis process first attaches load measurements to the primary system at the connections to the secondary network and solves the primary system. The result is then used as in-flows to the secondary system. The load is scaled to match the energy flow. Finally, the power flow on the secondary system is solved. Because the secondary system is large, this takes the bulk of the solution time.

Other vendor demonstrations at trade shows reveal other solutions for the overlapping display problem. One of the more popular approaches is to separate the lines by a small amount so that when the user zooms in on the drawing, the appropriate line can be easily selected. Other vendors with a GIS graphical front end or an AutoCAD front end can use layers to separate the primary and secondary circuits as well as different feeders.

Although EPRI had many of radial circuit models for several of the tools evaluated for this project, unfortunately, no urban LV network models were available for these tools.

6 FUTURE EFFORTS

EPRI's vision for distribution system analysis is for distribution planning, which is now predominantly done off-line, and on-line real-time simulation to merge in the SmartGrid of the future that many entities are now promoting. Load models will be updated within seconds or minutes from AMI devices that saturate the system. This poses many potential issues for distribution system analysis software. One issue is that solutions must take place in relatively short order (a few seconds or even several solutions per second). It is sometimes possible to solve radial systems piecemeal to improve solution performance, but urban networks must be solved intact. Ideally, radial systems should also be solved simultaneously, along with a portion of the transmission system. Otherwise, the true value of actions such as demand response or dispatching storage cannot be determined. The capability for meshed network modeling and solution is key to this.

Many proposals for addressing the anticipated large system simulation problem of the future involve the use of parallel processing. This is the approach advocated by the United States Department of Energy through its GridLab-D project at PNL. This area lacks both appropriate software development tools and methods for power system analysis by parallel processing. However, powerful desktop computers with eight processors are already available for less than U.S.$1000. Currently, the main application is gaming, but one can easily envision the day when distribution engineers have computers on their desktop with 16 or 32 processors. How can these be exploited for power system analysis problems such as analysis of urban networks? This is an area ripe for research.

Two additional topics for future EPRI research in the specific area of urban LV networks are (1) to identify the capabilities of various noncommercial tools and compare them to the tools offered by the commercial vendors, and (2) to support industry efforts to provide benchmarks for urban network tools to help those purchasing such tools evaluate them.

Some utilities are using in-house, custom-built programs for urban LV network analysis. It would be informative to identify these utilities and compare the capabilities they have implemented over the years with the offerings of commercial vendors. These custom programs might be an endangered species as utilities look more to commercial vendors to supply and maintain distribution system analysis software. The vendors generally do not develop capabilities for their tools for their own amusement. The fact that all the vendors who responded to the survey in this project indicate that they have already implemented urban LV network capabilities suggests that they believe there is a market for this kind of tool. One vendor clearly stated in a phone conversation to the Principal Investigator that he was responding to a request for quotation from a large utility for urban network modeling and analysis capability.

A void that has been identified in this project is the lack of appropriate urban network benchmarks for comparing analysis tools. It is recommended that EPRI consider means to support efforts by the IEEE Distribution Test Feeder Working Group in developing appropriate benchmarks for the following:

- Urban LV networks
- Annual simulations
- DG protection
- Microgrid simulations
- Distribution state estimation

Each of these areas has an impact on urban network tool development. Of these, only the DG protection benchmark is scheduled by 2011. The others will likely be delayed until 2012 or later, unless a suitable benchmark is contributed earlier (this is currently a volunteer effort, as are most IEEE efforts). If EPRI members desire benchmarks sooner, specifically directed research projects are recommended.

7 REFERENCES

1. B. Stott and O. Alsac, "Fast Decoupled Load Flow," *IEEE Transactions on Power Apparatus and Systems*. Vol. PAS-93, No. 3, pp. 859–869 (1974).
2. W. H. Kersting. 2007. "Distribution Feeder Analysis." In *Distribution System Modeling and Analysis, Second Edition*. 269–299. CRC Press, Boca Raton, FL.
3. J. Arrillaga and N. R. Watson. 2001. "Load Flow." In *Computer Modeling of Electric Power Systems, Second Edition*. 81–127. John Wiley and Sons, West Sussex, England.
4. John J. Grainger and William D. Stevenson, Jr., 1994. "Power-Flow Solutions." In *Power System Analysis*. 329–376. McGraw-Hill, Inc., New York.
5. L. R. Araujo, D. R. R. Penido, S. Carneiro Jr., J. L. R. Pereira, and P. A. N. Garcia, "A Comparative Study on the Performance of TCIM Full Newton Versus Backward-Forward Power Flow Methods for Large Distribution Systems," presented at the 2006 IEEE PES Power Systems Conference and Exposition (November 2006).
6. R. C. Dugan, William H. Kersting, Sandoval Carneiro Jr., Robert F. Arritt, and Thomas E. McDermott, "Roadmap for the IEEE PES Test Feeders," presented at the panel on Advances in Distribution System Analysis, Seattle, WA (March 2009).
7. *Guideline for Reliability Assessment and Reliability Planning–Evaluation of Tools for Reliability Planning*. EPRI, Palo Alto, CA: 2006. 1012450.
8. R. C. Dugan, "NEV Test Case," presented at the panel on Advances in Distribution System Analysis, Chicago, IL (April 2008).
9. W. F. Tinney and J. W. Walker, "Direct Solution of Sparse Network Equations by Optimally Ordered Triangular Factorization," *Proceedings of the IEEE*. Vol. 55, pp. 1801–1809 (1967).

A VENDOR SOLICITATION LETTER

Letter Sent to Vendor of Distribution System Analysis Software

The following letter was sent as an e-mail to 10 distribution system analysis software vendors identified by the principal investigator and project advisors.

To: Electric Power Distribution System Analysis Software Vendors

I am the Principal Investigator on EPRI project P30.006 (see attached description). My main task is to write a Technical Update on the status of available tools for analyzing highly meshed secondary (LV) network systems found in urban areas. In most utilities, the Distribution department is responsible for any analysis done on these networks. The tools for representing distribution systems often are designed for radial system analysis and have limited capabilities for modeling meshed networks. Utilities often use custom in-house tools or tools intended for transmission network analysis to study secondary network systems.

Funders of this project, who are, or could be, utility users of software like yours, are interested in tools that integrate better with their distribution system analysis tools, or that might be replacements for their present tools. This project is to determine the present and future (near-term) capabilities for meshed network solution of various tools the project advisors have identified. Therefore, if you are receiving this, one or more of the tools you offer have been identified, or I think you might be offering one or more tools that would be beneficial to the project funders.

While I am somewhat familiar with most of the commercial tools the funders have asked me to look at, I am not completely up-to-date on all features of the tools. I can make guesses about your product's capabilities from public literature and our knowledge of the product, but I would rather have you provide a statement describing the capabilities of your tools for secondary network analysis. Your statement will be included in the report as being factual and coming from the vendor, which will be identified. While existing capabilities are of most interest, you may also choose to discuss any near-term plans you might have for incorporating, or updating, secondary network analysis capabilities.

The first draft of this report is due 1 Nov 2009. Please respond by 20 October.

The primary applications are power flow and short circuit analysis, but there is also interest in harmonics, distributed generation, and such things as distribution state estimation. See the list below.

The report will be distributed only to utility project funders initially, but keep in mind that after 5 years the report could become public domain (some EPRI reports do). While EPRI will control the distribution of the report, information you provide may be inadvertently disclosed by its recipients. Therefore, be careful about including any information that you consider to be sensitive with respect to competitors in your product area.

Please address only your product's capabilities; avoid comments about competitive products.

The following is a list of issues and capabilities we are interested in. Briefly address any that are relevant to your product. Feel free to mention capabilities or features of your product that I have omitted from the list that you feel are important to secondary network analysis. I am expecting no more than a paragraph on each issue/capability you choose to address. Please limit your total response to approximately 5 or 6 pages. A digital format that I can strip into the report would be appreciated.

Tool Description

– Name
– Version

Network Solution Capability

– Radial only
– Weakly meshed networks
– Highly meshed networks
– High R/X limitations, if any
– Size limitations, if any
– Other limitations

Circuit Model

– Positive-sequence power flow only
– Symmetrical component impedance model (Z1, Z0)
– Full unbalanced 3-phase impedances
– Higher phase orders, double circuits, etc.
– Per unit model vs. actual values
– Single voltage level vs. multiple voltage levels

Solution Capabilities for Highly meshed Networks

– Power Flow
– Short Circuit
– Harmonics
– State Estimation
– Electromagnetic Transients
– Distributed generation
– Machine dynamics
– Inverters dynamics
– Renewable (variable) generation

Data Sources

– Database (type, whether proprietary or open, etc.)
– Text files
– Proprietary binary files
– CIM interface
– Multispeak interface
– GIS interface
– Export for other programs

Load Modeling Capability

– Constant kVA (P + jQ)
– Constant Impedance
– Constant Current
– Other voltage-dependent models (CVR, etc.)
– 1-, 2-, and 3-phase loads
– MV/LV transformer connections
– Load allocation from connected kVA
– Load allocation from kWh billing
– Capability for incorporating AMI data and SCADA data
– Capability for loadshapes (daily, weekly, yearly, etc.)
– State estimation capability

Feel free to contact me by phone or e-mail if you have questions. I'll be happy to discuss this with you.

Roger C. Dugan, FIEEE
Sr. Technical Executive
EPRI
942 Corridor Park Blvd,
Knoxville, TN 37932
tel: 865.218.8074
fax: 865.218.8001
Cell: 865.405.6926
rdugan@epri.com

Description of P30.006 Attached to Solicitation Letter

P30.006 Urban Network Simulation Tools (067435)

Issue

Utilities that serve customers using networked secondary systems require technologies to be able to model the system and perform load flow and other circuit analyses on both the primary and networked secondary. Utilities may utilize commercially available load flow products to model their radial systems, but many older products are unable to accurately model and perform analyses on meshed secondary network systems sourced from multiple primary feeders. Consequently, many utilities are using legacy systems to perform network analysis—systems which may lack the ties to GIS systems, graphical display ability, ability to easily analyze "what if" scenarios, ability to reflect real-time system condition changes, and other features of newer, vendor-developed products.

Utilities can benefit from assistance in understanding what vendor products are currently available to model and perform analyses on network systems and what features are contained within these products.

Description

EPRI will research commercially available tools for modeling network systems (primary and secondary) and performing network circuit analyses. EPRI will work with network utilities to develop a desired features list, including attributes such as graphical displays, ability to perform primary feeder fault analysis, ability to perform networked secondary load flows, ability to perform PQ analyses, and interfaces with mapping systems, GIS data, AMI data, CIS data, and SCADA/remotely monitored data to create accurate network models. EPRI will produce a matrix of vendor product offerings with available features that support network planning, design, and operations.

Value

- Research will summarize features that are important to members.
- The research will enable utilities to understand what functionality is available in the marketplace and ascertain whether the features of commercially available products will meet their needs, including secondary modeling and analysis.
- Analysis will result in a matrix that shows features of commercially available products, which will help utilities evaluate vendors and select products.

How to Apply Results

Utility engineers and network system operators will be able to compare the functionality of commercially available products to their specific network analysis and modeling needs. This comparison will help them develop a practical technology implementation strategy and prepare a justification for the investment in a vendor modeling and analysis software implementation and integration. Ultimately, the implementation of network modeling and analysis software will help engineers develop optimum system reinforcement plans to meet capacity and reliability expectations. It will also aid operators in optimally configuring the system based on real-time conditions.

EPRI 2009 Portfolio p. 11 30 Underground Distribution Systems

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Urban Network Simulation Tools	12/31/2009	Technical

Vendors to Whom the Solicitation was Sent

1. OpenDSS (EPRI)*
2. Cyme/Cooper CYMDIST*
3. Advantica SynerGEE Electric
4. Milsoft Windmil*
5. EDD DEW*
6. Telvent DMS*
7. EDSA DesignBase 2.0
8. Etap
9. EasyPower*
10. Aspen Distriview*

* Responded to the solicitation.

B EPRI OPEN DISTRIBUTION SYSTEM SIMULATOR (OPENDSS) RESPONSE

Tool Description

The Open Distribution System Simulator (OpenDSS, or simply, DSS) is a comprehensive electric power system simulation tool designed with an emphasis on electric utility distribution systems. Development of the tool began in 1997 by Electrotek Concepts, Inc. and the program was purchased by EPRI in 2004. The tool was designed to be used by consultants and research engineers on advanced distribution system analysis problems. EPRI made a decision in 2008 to provide the program as open source (on SOURCEFORGE.NET) to spur the advancement of the Smart Grid.

The program basically supports all rms steady-state (i.e., frequency domain) analyses commonly performed for utility distribution systems. In addition, it supports many new types of analyses that are designed to meet future needs, many of which are being dictated by the deregulation of U.S. utilities and the formation of distribution companies worldwide. Many of the features found in the program were originally intended to support distributed generation analysis needs. Other features support energy efficiency analysis of power delivery and harmonics analysis. The DSS is designed to be indefinitely expandable so that it can be easily modified to meet future needs.

Through the program's COM interface, users are able to add new solution modes and features externally and perform the functions of the simulator. This makes it a valuable tool for researchers who are evaluating new distribution system analysis methods and simulating the impacts of new types of loads or power resources.

The responses to the items in the questionnaire are listed below.

Network Solution Capability

The program was designed from the ground up to solve highly meshed networks. One need this program was designed to address was the benefit of DG installed on the distribution to the transmission system. This requires the ability to solve networked systems. Also, the need to represent short circuit contributions from DG and harmonic flows results in a requirement for meshed network solutions.

Therefore, OpenDSS has only a meshed network solver that it uses for all functions. The program currently does not have a radial circuit only solver. A legacy method has been withdrawn from the program. Presently, only the EnergyMeter object in the program keeps track of radial circuits. That function is separate from the solution algorithm and is mainly used for tabulating capacities, losses, etc. post-solution.

The program presently has the following solution algorithms built in:

1. A simple fixed-point iterative solution employing the compensation method for nonlinear loads. This suffices for nearly all distribution system models.
2. A Newton-based method (not the typical "Newton-Raphson" power flow method) for systems that require a more robust solver than the default solver. This is approximately half as fast as the default method.
3. A direct solution (non-iterative) that linearizes the model. Can be used to approximate the power flow, but the main purpose is for harmonics, short circuit, and dynamics simulations.

The program can solve radial, weakly meshed, and highly meshed circuits with equal ease. The program makes no attempt to determine the structure of the circuits; it is not necessary.

The solution is performed with full representation of complex impedances and there are no know limitations with respect to R/X ratios.

Memory for each elements of the circuit model is dynamically allocated. Thus, there are no specific limits on numbers of buses or any particular type of element. We have solved 3-phase circuits in excess of 30,000 buses and still have not taxed the memory limits of the Windows operating system. Maximum system size is not known.

Circuit Model

The normal circuit model is a fully coupled n-phase model. Most circuit elements have a default number of phases of 3; some elements, such as Fault objects have a default of 1. However, most elements can have nearly any number of phases if the data can be supplied for the models. We will commonly model lines built on the same pole or having multiple neutral conductors (from telecommunications circuits, etc.). Thus, there are very few limits on what may be modeled.

Users may chose to build a positive-sequence equivalent model. There is a command in the program that will attempt to automatically convert a 3-phase model to a positive-sequence equivalent.

Lines may be defined using positive- and zero-sequence impedances although the program uses full matrices in the phase domain for solutions.

The program uses actual volts, amps, and ohms (actually Siemens) for its calculations. Some models can be defined using per unit, or percent, values. Also, some reports will sequence components from the results of a solution. This is for the convenience of the user. The program itself does not need per unit values or symmetrical components to perform its solution.

There is no limit on the number of voltage levels that may be represented in a circuit. Transformers are modeled explicitly and voltages are automatically transformed. This approach allows for the simulation of unusual transformer connections one may encounter or wish to explore. This is a common use of the program.

Solution Capabilities for Highly Meshed Networks

All the solution modes available in the program can be performed on highly meshed networks.

These solution capabilities include (from the list in the questionnaire):

- Power flow
- Short circuit
- Harmonic flow
- Distributed Generation with machine dynamics
- Variable generation shapes with renewable generation

Data Sources

The OpenDSS program was designed for a consulting engineering environment where distribution system data was expected in a wide variety of forms. The program does not use a database. Rather, it uses a scripting language to define the circuit and control the operation of the simulator. These scripts may come from text files, manual entry by the user, or through the COM interface from another program. Regardless of source, the scripts are in the same format.

The scripting language is designed to accept circuit data, which can be quite complicated, from as many different sources as possible with the least amount of conversion.

Nearly all data exchange is text, although binary data can be transferred through the COM interface.

There is a CIM export function and the CIM import function is under development. The program does not yet interface directly to MultiSpeak.

Results of calculations are typically exported in CSV format for easy transfer to post-solution analysis tools such as those in Microsoft Office or in Matlab.

Load Modeling Capability

Because it was originally designed to support analysis of DG impacts on distribution systems, the DSS was one of the first distribution system analysis programs to be designed with the following recognition of load modeling issues:

- Several types of loads may exist at one bus.
- To see the correct answer with respect to DG and varying load, one needs to simulate over long periods of time (e.g., a year).

Thus, the DSS was designed to support multiple load models (there are currently 7) that can be mixed and matched at each bus if necessary. The program was also designed to quickly computer time series simulation and have a means to collect the results of long simulations. The program has been used extensively to model CVR and can allocate loads using connected kVA or kWh billing.

Transformers are modeled explicitly. Therefore, the common 120/240V split-phase service transformer is not a modeling problem as it is in some programs. The program can also handle open-wye/open-delta and other highly unbalanced connections.

The Load element, like other elements, is a n-phase model. There are special defaults for 3-phase loads to make it easier to specify, but phase order is not generally an issue.

C CYME CYMDIST RESPONSE

Cyme submitted the datasheet for the CYMDIST (SUB/SUBNET) module. This can be obtained from their website. The following is the section pertinent to urban LV networks.

Secondary Network Analysis

The Secondary Networks module is an add-on to the CYME Power Engineering Analysis Software. It is designed to perform the power flow and short circuit analysis of heavily meshed secondary network distribution systems for any voltage level.

The Secondary Networks module enables the user to build the secondary grid by including the complete vaults with their transformers and protective devices, the secondary lines or cables, as well as the distribution transformers.

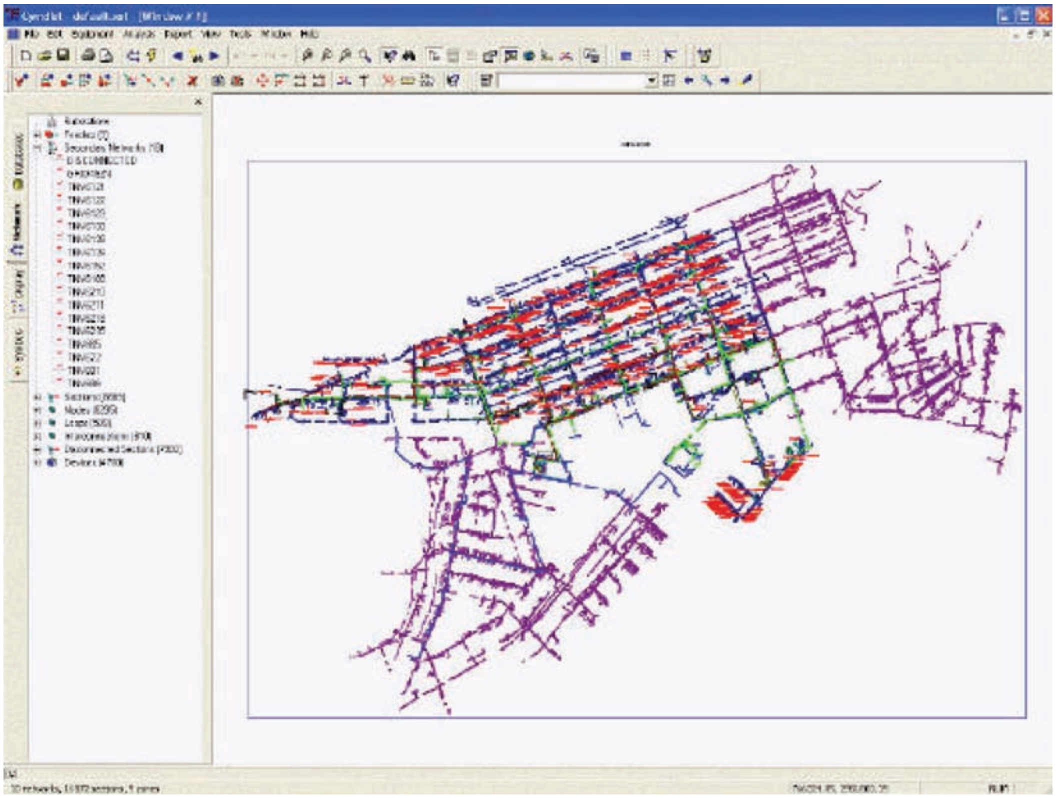
It uses the graphic editor of CYME to model the secondary network and display the results of the power flow and short circuit simulations on the one line diagram. Any portion of the system can be selectively visualized in detail and system-wide results can be viewed for any type of simulation.

The module also includes a comprehensive suite of presentation tools for selective visualization and effective management of large data sets, like spreadsheets, rapid graphics and a multitude of context-dependent reporting facilities such as:

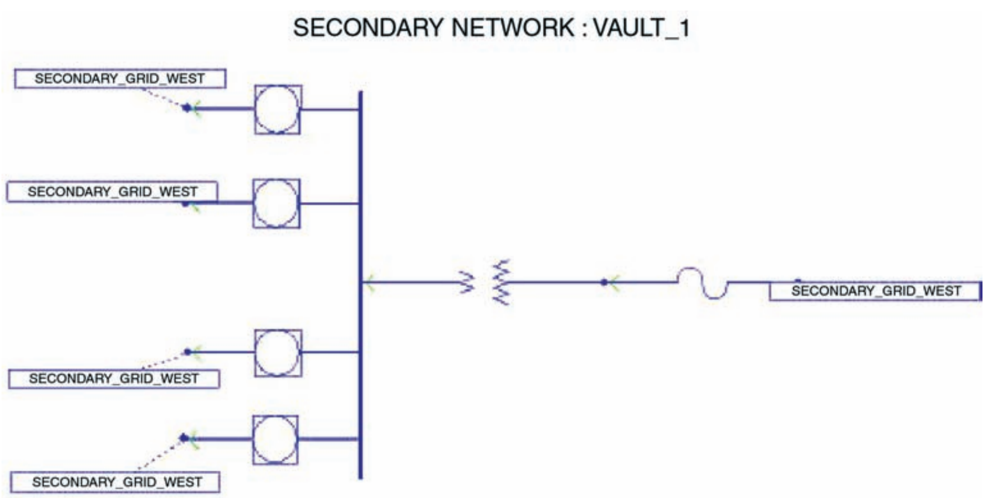
- Full voltage drop and short circuit reports
- Overloaded conductors and devices
- Abnormal Conditions
- And others

Unique Capability

The CYME Substations and Sub-Network Analysis module and the Secondary Network Analysis module greatly enhance the capability of our CYME power system analysis software by including, in addition to the primary feeders, the substation detailed representation and the secondary grids all the way down to the customer's transformers.



Secondary Network



Secondary Vault Detailed View

D MILSOFT WINDMIL RESPONSE

Modeling Urban Low-Voltage Networks using Milsoft WindMil Engineering Analysis Software

Tool Description

Name WindMil
Version Gold Version 7.3; beta version 8.0

Network Solution Capability

WindMil is radial in structure but can solve a network system of any size and complexity by inserting one "pooped" status switch in each looped path.

This allows the database to be Parent-Child in structure while and the Load Flow and Fault algorithms looped, since a Looped switch looks like and open switch to the database system but is a closed switch to the Load Flow and Fault Current algorithms.

No limitations are imposed given that memory size must be sufficient to hold entire looped system during solution.

Solution time will increase with size of networked system.

Circuit Model

The WindMil Circuit Model is:

- Full unbalanced 3-phase impedances and loads.
- With the ability to model any number of overhead circuits in physical parallel and any number of underground circuits in physical parallel.
- Algorithms use per unit and reporting and display is user selected per unit, percentage, or volt/amp.
- All valid combinations of transformer windings may be modeled resulting in any combination of voltage level and Delta/Wye configurations. This includes true center tap secondary voltages such as 120/240 and 4-wire delta three phase secondary's with one leg of delta grounded at the center tap.

Solution Capabilities for Highly Meshed Networks

WindMil can solve Looped Networks for:

- Power Flow (Load Flow)
- Short Circuit (Fault Current)
- Fault Flow → Calculates all circuit voltages and currents for a given fault type at a selected location
- Distributed Generation

Note that we are working on an interface with OpenDSS to accomplish all applications possible with OpenDSS.

Data Sources

WindMil is:

- Open Database (SQL after Jan 1st 2010)
- With Text files possible
- Multispeak certified
- Has GIS interface and model can be platformed in ESRI
- Has Imports from other programs developed and can develop exports to other programs

Load Modeling Capability

WindMil can model:

- Constant KVA
- Constant Impedance
- Constant Current
  - Note any combination of three load types is possible
- Any valid combination of 1, 3 and 3 phase loads in Wye or Delta connected configurations
- Any standard transformer connection including center tap
- Load Allocation from
  - Connected kVA
  - kWh billing
- Has capability for incorporating AMI and SCADA data

E EDD DISTRIBUTED ENGINEERING WORKSTATION (DEW) RESPONSE

Highly Meshed Network Analysis with Dew Version 9.3.0.R1

The **D**istributed **E**ngineering **W**orkstation may be used by personnel throughout an organization, all sharing the same model, where each user may be running different analysis calculations on the model. The Dew power flow solves multi-phase, unbalanced, highly meshed networks. There is no limitation on the size of system that may be solved. Loops created by short cables running in parallel may be modeled. Single-phase loops and two-phase loops may be modeled inside of three-phase loops.

Figure 1 shows a downtown network modeled in Dew that has 29 primary feeders and approximately 900 independent loops. Dew was used to re-design this network and is used to check feeder contingencies. The Dew power flow can solve the network of Figure 1 in 983 milliseconds using a single processor operating at 2.0 GHz.

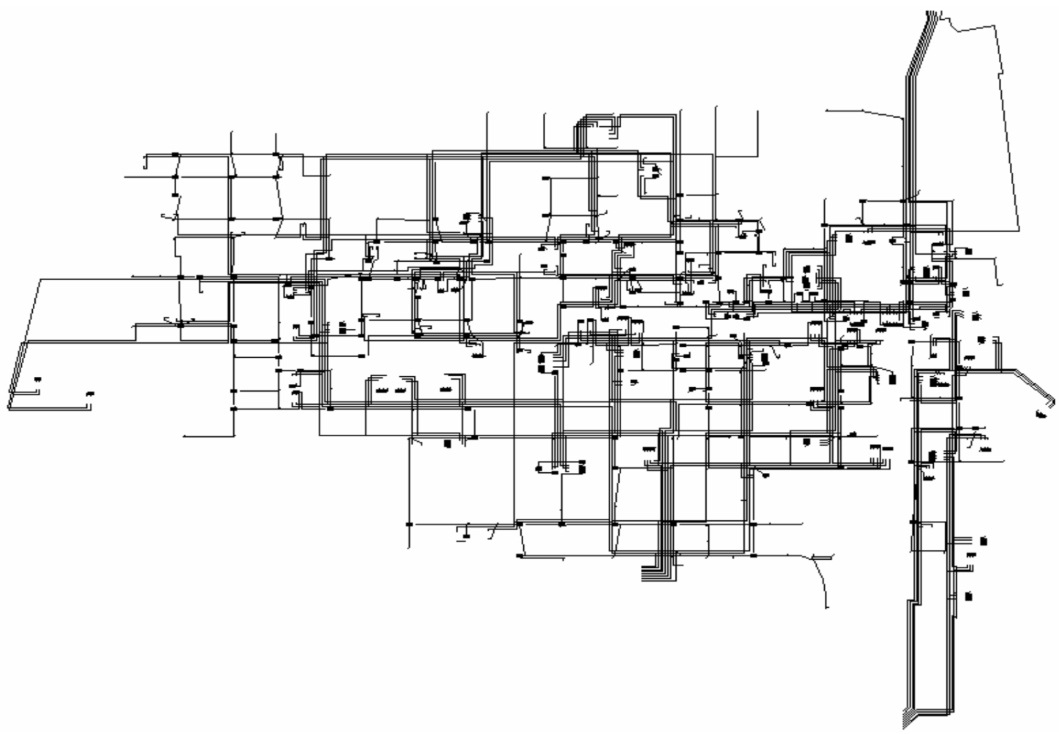


Figure 1
Dew model of downtown network

Figure 2 shows a secondary network modeled in Dew. The colored cables illustrate the results of a cascading, cable failure analysis, where 3 primary feeders for the network are outaged at peak load. The primary feeders for the network of Figure 2 are shown in Figure 3. As indicated in the Figure 2 caption, the cables shown in green were the first to fail due to severe overloading (i.e., cascade level 1), followed by the cables shown in red (i.e., cascade level 2). Cables shown in blue failed between cascading levels 3 and 5. Cables shown in pink failed at cascading levels 6 and higher. Customers connected to the cables shown in black suffered no power loss.

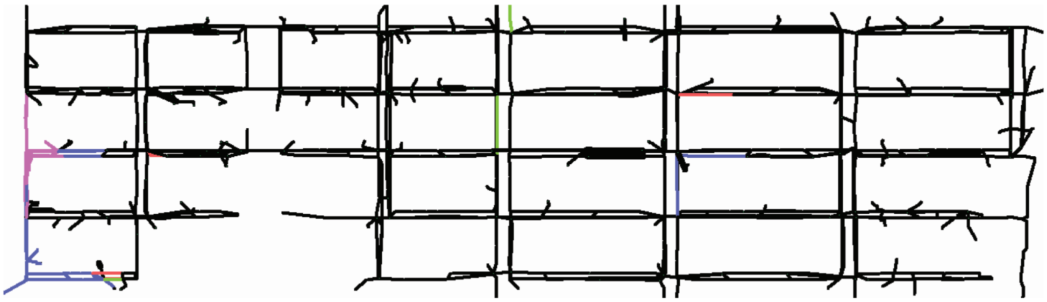


Figure 2
Cascading cable failure analysis for outage of three primary feeders:
Black => no power loss;
Green => first cables to fail or cascade level 1;
Red => second cables to fail or cascade level 2;
Blue => cascade levels 3–5 cable failures;
Pink => cascade level 6 and higher cable failures

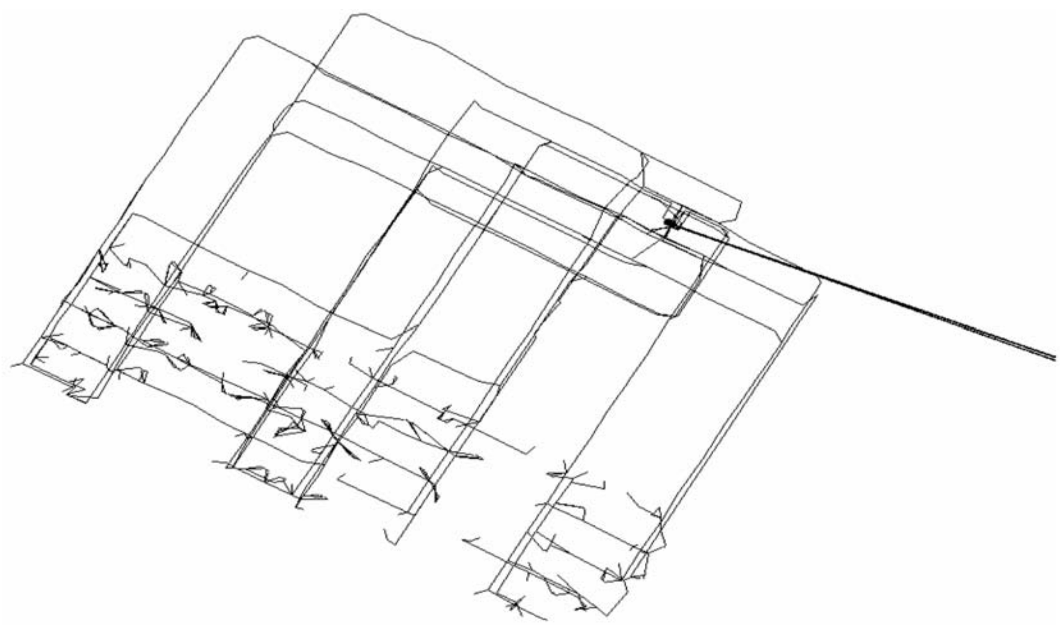


Figure 3
Primary feeders for secondary network shown in Figure 2

Multi-phase self- and mutual-impedances and admittances in ohms are used in the analysis. Lines may be modeled with per unit values, where the per unit values are converted to ohms in analysis calculations. Any number of voltage levels may be included in the model. Network protectors and current limiters along with distributed generation, including synchronous, solar, wind, and fuel cell generation, may be modeled.

Transmission substations, transmission lines, and distribution substations may be included in the model. Note that the lines shown at the right of Figure 3 model eight transmission lines feeding a distribution substation which contains five transformers, which are not visible in the figure due to the zoom level. Substation models may include bus bar ratings, breakers, relays, and other equipment.

Analysis Capabilities for Highly Meshed Networks Analysis capabilities include power flow, fault analysis, Monte Carlo reliability analysis, automated contingency analysis, model validation, reconfiguration for restoration, **D**istributed **E**nergy **R**esource adoption analysis, real-time reliability analysis, and time-series analysis.

To increase solution speed, the power flow calculations may be distributed across processors (see "Distributed Algorithms with Theoretic Scalability Analysis of Radial and Looped Load Flows For Power Distribution," F. Li, R. Broadwater, Electric Power Systems Research, volume 65, issue 2, pp 169–177, March 2003). For instance, the primary system shown in Figure 3 may be solved on one processor and its corresponding secondary system shown in Figure 2 may be solved on another processor, where the two solutions are matched at the model boundaries, which in this case are network transformers.

The cascading failure analysis shown in Figure 2 was calculated using Monte Carlo analysis coupled with power flow analysis. The Monte Carlo analysis can predict CAIDI and CAIFI for individual customers, SAIDI and SAIFI for the system, and loss of load probabilities. Contingency analysis is automated to check all single- and double-primary feeder contingencies.

In fault analysis both fault currents and voltages that exist during the fault are predicted. Fault characteristics of inverter interfaced generation are modeled.

The model validation algorithm validates the model performance against SCADA measurements, and as part of this validation adjusts customer loads so that power flow calculations match closely to SCADA measurements. Load scaling values required to match SCADA measurements that are not statistically expected are flagged. This has been used to detect bad SCADA measurements or unknown switch operations and configurations.

DER adoption analysis by customer class is provided. Percent growth rates of plug-in electric hybrid vehicles, solar generation, and others may be concurrently analyzed, and DER growth levels at which the network reaches capacity/service voltage limits determined.

Figure 4 illustrates the real-time reliability analysis architecture which makes use of model validation, a short term Monte Carlo forecast, and automated contingency analysis running on different processors. This architecture employs an assembly line of analysis workers with circuit queues being used to store and retrieve work products. That is, the circuit queues store models that have been modified by assembly line analysis workers and that are queued for additional analysis or visualization by display engines.

Time Series Analysis Dew comes with time series storage where analysis calculated values and their corresponding SCADA measurements are stored along with system events such as breaker operations. Automated replay of the time series SCADA and event storage may be performed for user selected time periods, with analysis calculations running on each SCADA sample. Error statistics between calculated values and their corresponding SCADA measurements may be developed and are used by the model validation algorithm in detecting unusual SCADA measurement events. Dew has been used to find bad SCADA measurements.

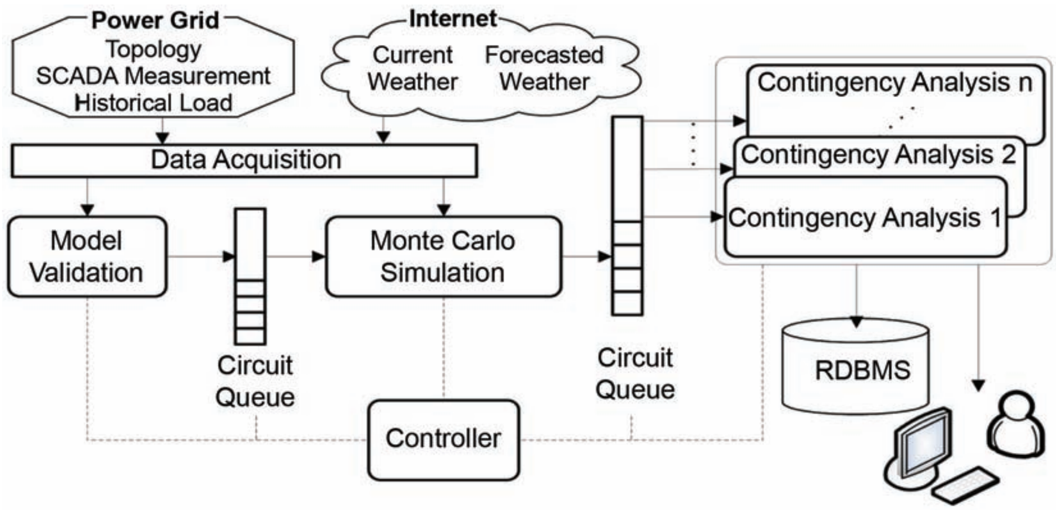


Figure 4
Real-time reliability analysis architecture with assembly line analysis workers

Load Modeling Capability Load models incorporate customer class load research statistics, individual customer kWHr billing measurements, individual customer demand measurements, individual customer hourly kW and kVar measurements, motor loads, measurements for any type of load, constant power loads, constant impedance loads, constant current loads, and voltage dependent loads. Daily, monthly, and annual load patterns may be analyzed. (*see "Estimating Substation Peaks From Load Research Data," Robert Broadwater, Al Sargent, Abdul Yarali, H. Shaalan, Jo Nazarko, IEEE Transactions on Power Delivery, Vol. 12, No. 1, pp. 451–456, January 1997*). Load research statistics may be weather dependent. Using weather dependent customer class based load models, Dew load forecasting capability has been used in bidding aggregated, distributed generation into the MISO market.

One-, two-, and three-phase loads may be modeled either as phase-to-return path or as phase-to-phase. Load growth factors are modeled as a function of load type and may be specified for each individual customer or on a system wide basis. Each load may have its own voltage dependency factor and voltage dependency factors may also be specified on a system wide basis. If a voltage dependency factor or load growth factor is not specified for an individual load, then the factor specified for the system wide analysis is used. A customer's load may be modeled with 8760 hourly values. Dew has algorithms for processing raw load research data to create customer class based load research statistic models and for tuning the models so that load predictions agree closely with SCADA measurements.

Renewable Generation and Inverter Dynamics Modeling Renewable generation is modeled. Field measurements of renewable generation may be stored in a time series format and used to drive the simulation. An interface to the National Renewable Energy Lab's solar generation server is used to analyze solar generation sites across the United States, where 8760 hours of generation may be modeled. Inverter dynamics may be modeled. Figure 5 illustrates a dynamic response calculated in Dew for an inverter interfaced fuel cell.

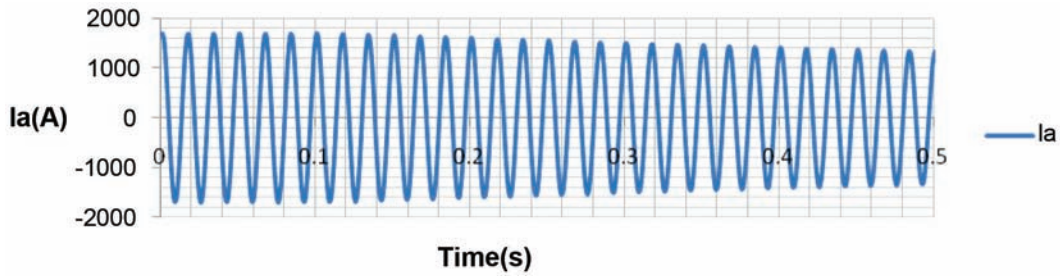


Figure 5
Example of inverter interfaced fuel cell generation simulation

Validation and Verification of Dew Calculations The Dew power flow has been validated against SCADA measurements associated with a first contingency of a highly meshed network, and analysis predictions had an average error of 5% when compared against 447 primary feeder and network transformer measurements. Other field validations on Dew calculations have been performed, including predictions involving voltage regulators, switched capacitors, and distributed generators (*see "Comparison of Analytical Results with Measured Results," Murray W. Davis, Robert Broadwater, Joshua Hambrick, CEC D-2.3.10 NREL D-1.6b Contract ZAT-5-32616-06, January 9, 2007*).

Detroit Edison has validated the Dew fault analysis calculations against field measurements of fault currents, with an error of approximately 2% between measured fault currents and calculated fault currents. The Dew power flow and fault analysis have been verified against both IEEE standard transmission and distribution circuit models and the Dew training database comes with IEEE standard models. The Dew power flow has been independently verified by New York University to be accurate and robust (*see "A Robust Multi-phase Power Flow for General Distribution Networks," M. Dilek, Francisco de Leon, R. Broadwater, accepted for publication in IEEE Transactions on Power Systems*). The Monte Carlo reliability analysis has been validated against field measurements of first, second, third, and forth order primary feeder contingencies (*see "A Graph Trace Based Reliability Analysis of Electric Power Systems with Time Varying Loads and Dependent Failures," D. Cheng, D. Zhu, R. Broadwater, S. Lee, scheduled for publication in Electric Power Systems Research Journal*).

Load Priority and Mission Modeling Load priorities are modeled, and load priorities may be a function of mission, where a mission may be to fight fire or to employ rapid transit to evacuate population. In an Integrated System Model the reconfiguration for restoration algorithm may be employed to determine switching operations for restoring power to critical customers (*see "A Heuristic Nonlinear Constructive Method for Distribution System Reconfiguration," T. E. McDermott, R. Broadwater, IEEE Transactions on Power Systems, Vol. 14, No. 2, pp. 478–483, May 1999 and "Reconfiguration of Interdependent Critical Infrastructure Systems," by David Kleppinger, R. Broadwater, Charlie Scirbona, scheduled for publication in Electric Power Systems Research Journal*).

Model Management with Topology Iterators Topology iterators are used by algorithms, such as power flow or reliability analysis, to access model components. Algorithm calculations are implemented in terms of the topology iterators. Only the topology iterators that are affected by a configuration change need to be updated, resulting in fast analysis. Because a matrix that captures the topology of the entire system is not used in the calculations, the model and the algorithms that operate on it can be readily split across processors to increase the speed of solution.

Systems with 2 million nodes can be opened in 30 seconds. The Dew circuit server may be used to move selected circuits from one Dew instance on one processor to another Dew instance that may exist on a different processor. Dew circuit queues may be used to move models between analysis workers, as illustrated in Figure 4.

Interfaces to Other Data Dew has interfaces to five different GIS systems. SCADA interfaces use OPC/ICCP, CORBA, PI time series storage, and Web interfaces. Interfaces to real-time weather data, to day-ahead weather forecasts, to once-per-minute lightning data, to outage data, to trouble call data, to fault indication, to fault current and voltage waveform measurements, and to SCADA measurements of voltage magnitude, current magnitude, and power factor have been implemented. Interfaces to customer load information, including monthly kWHr measurements, demand measurements, and hourly load measurements are implemented. Web services may be used to import Dew models from other systems and to export Dew models to other systems. Flat text files may be used to obtain Dew model topologies along with results from power flow calculations. Dew model topology and calculated results may also be obtained from "kml" files. Thus, any system that can import the kml file format can display Dew model topologies along with calculated values.

Programmer Development Environment A C++ programmer's development environment, including a project template for setting up an analysis application interface, is provided and is in use at national labs and utilities. The programming environment may be used to import and attach all types of data and measurements to the model and also to develop analysis applications that run on the model and its attached data and measurements. An analysis application may obtain results from any other analysis application in Dew. This feature allows reuse of all existing calculations in a new analysis application, and provides for rapid application development with emergent problems.

The relational database schema, time series storage, and the in-memory layout of data are published. No data is stored in proprietary or binary formats. Dew can work with any relational database that is ODBC compliant. The Dew circuit model may be stored in a relational database and to a flat text file.

F TELVENT DMS RESPONSE

Telvent DMS submitted a 16-page document, a large part of which can be found on their website. Essential excerpts relevant to the urban LV network issue are included here.

1. Telvent DMS Introduction

[Content omitted.]

Telvent DMS is the software engineering company for research, development and software engineering in electrical power systems, specially devoted to Distribution Management Systems (DMS), but experienced in Energy Management System (EMS) as well. Company gathers over 500 experts in power and computer engineering from Novi Sad (north of Serbia), with strong relations with University and Power Utilities of Serbia.

This software development team is the biggest team of its kind in the world and counts over 500 outstanding experienced power and software engineers which are employed in development of power engineering application software. Expert resources of TELVENT DMS, besides exceptional qualification, motivation and working discipline also have a very competitive price.

Telvent DMS is the joint venture of **DMS Group** Novi Sad Serbia and **Telvent Energia** SA. Spain. Telvent is the international leading company in areas of information infrastructure, automation, telecommunication, energy and environmental protection. DMS Group is the leading software engineering company in area of power engineering and the part of technology park of University of Novi Sad.

2. EPRI Questions

2.1 Total Description and Version

Telvent DMS system (TDMS) description is provided in the Chapter 1.

The last version of Telvent DMS system is Version 2, release 71.96

2.2 Network Solution Capability

TDMS sophisticated algorithms are managing radial and meshed power networks of medium voltage (1–150 kV) and low voltage (under 1 kV).

There is no theoretical size limitation for algorithms applied, except hardware performance limitations. Network up to 1.000.000 nodes can be efficiently managed.

2.3 Circuit Model

TDMS network model supports:

- Positive sequence power flow for balanced networks,
- Full three-phase power flow for un-balanced networks as well as for two-phase and one-phase network parts,
- Symmetrical component impedance model,
- Per unit model,
- Multiple voltage levels.

2.4 Solution Capabilities

TDMS provides power applications for radial and meshed power networks including high efficient State Estimation and Power Flow solution, Short-Circuit analysis, Harmonic Analysis, Distributed Generation modelling, Motor start dynamics and many other in set of over 40 different power applications:

1. Network model
2. Topology analyzer
3. Load Flow
4. State Estimation
5. Performance Indices
6. Fault Management
7. Incident Management
8. Supply Restoration
9. Large Area Restoration
10. Switching Sequence Management
11. Under Load Switching
12. Load Shedding
13. Fault (Short Circuit) Calculation
14. Relay Protection
15. Energy Losses
16. Operation Losses
17. Reliability Analysis
18. Optimal Network Reconfiguration
19. Voltage Control
20. Var Control
21. Volt/Var Control
22. Voltage Reduction
23. Network Automation
24. Short-term Load Forecasting
25. Medium-term Load Forecasting
26. Long-term Load Forecasting
27. Load Management
28. Contingency/Security Assessment
29. Operation Improvement
30. Historical System
31. Network Development Planning
32. Thermal Monitoring
33. Breakers/Fuses Capacity
34. Optimal Capacitor Placement
35. Remote Terminal Unit Placement
36. Motor Start
37. Dispatcher Training Simulator
38. Network Reinforcement
39. Temporary elements
40. Harmonic Analysis
41. Work Order Management

2.5 Data Sources

TDMS has powerful relational database (Oracle, MS SQL server) to manage network electrical data and to provide open data access and extensions of database (asset data). Internal model used by applications is based on SQ Lite database.

TDMS provides an interface component which is able to receive data from external GIS systems (GIS Adapter), which can receive either a bulk data export or incremental data in XML format, normally using web services for communication. Recommended GIS system is ArcFM extension of ESRI ArcGIS platform, but also TDMS has a lot of references in integration with third party GIS systems and various data sources (ArcFM, SmallWorld, Intergraph, Informix,...).

TDMS supports CIM and Multispeak interface for import or export to external systems.

2.6 Load Modeling Capability

Load modeling and State Estimation is core functionality of TDMS which provides high precision of Power Flow calculation and basic input data for all other power applications:

- Load models supported are: Constant kVA (P,Q), Constant impedance, Constant Current (I, cosphi).
- Loads are modeled as 1, 2 or 3-phase loads.
- All MV/LV connections (European and American) are supported.
- Using Load profiles (load shapes) is basic approach and functionality in TDMS. Load shapes are created for typical days and typical seasons.
- Peak indicators (local load indicators) can be indicated by measured values, connected kVA or kWH billing.
- AMI data or SCADA profiles are incorporated in getting higher precision of profiles.

3. Low-Voltage System

LV network model is complex and includes a lot of different LV equipment, as well as a large database with LV network model and data. Therefore, LV network is managed by separate DMS module (LV server) and network model, such that is not affecting performance of the main DMS modules for MV network. LV network module is able to interface with Metering System to import energy data about consumption and load profiles, as well as with Customer Information Systems to import customer data.

3.1 User Interface

LV network is treated as a separate layer on Telvent DMS distribution network solution and geographic map of the area. The following features are available:

- MV and LV network of the area,
- LV network only,
- One or more selected LV networks (each fed from one MV/LV substation) with arbitrary zoom.

The appearance of LV networks can be customized, for example the entire LV layer can be visible for zoom levels above a specified value, or only LV network belonging to selected MV/LV substation can be displayed. On the LV network layer, customer connections are displayed as well with the corresponding data. User interface also provides various reports, especially tabular lists of all consumers (names, addresses, identification numbers etc.) supplied from selected MV/LV transformers or LV feeders.

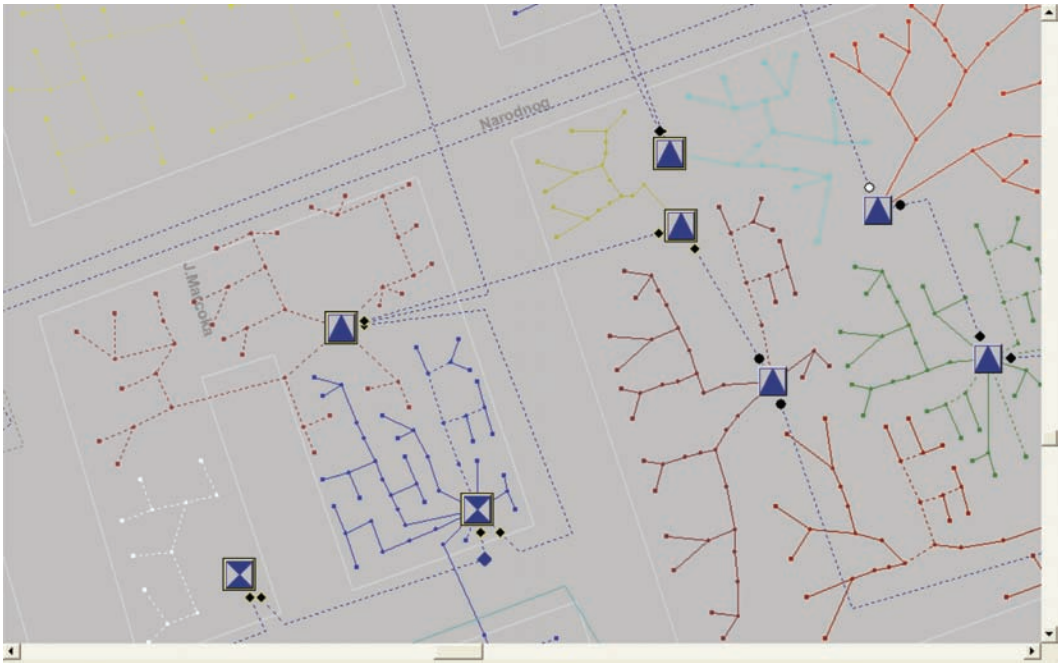


Figure 1
Geographical view of LV network, together with MV network, topology analyser is coloring different LV transformer areas

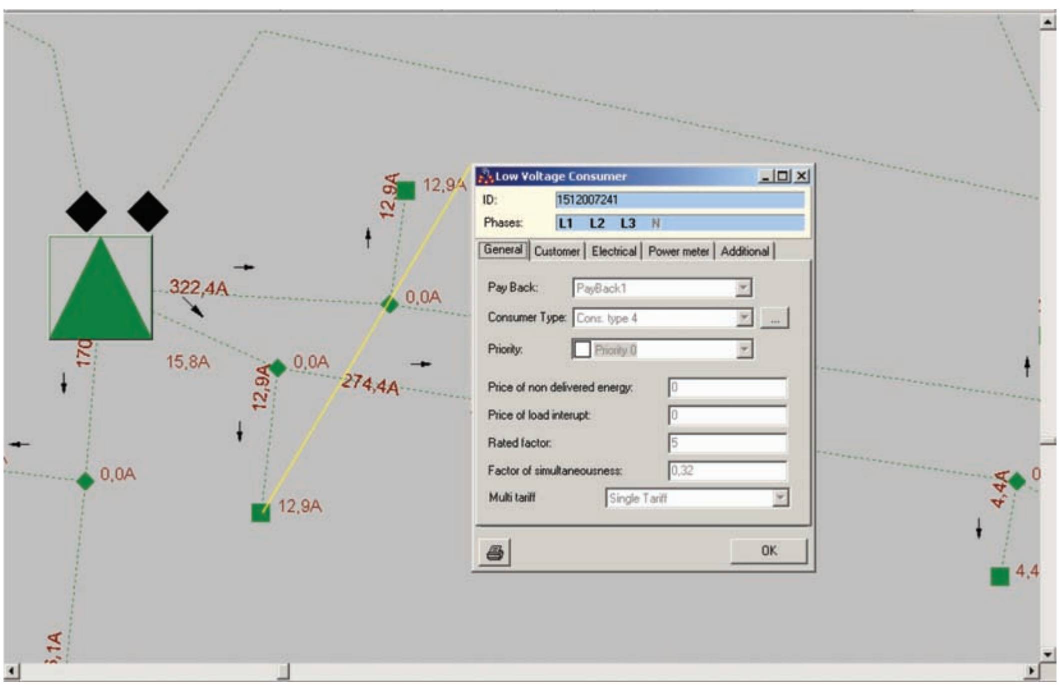


Figure 2
LV network: Load flow results are presented beside LV lines and the example of customer data

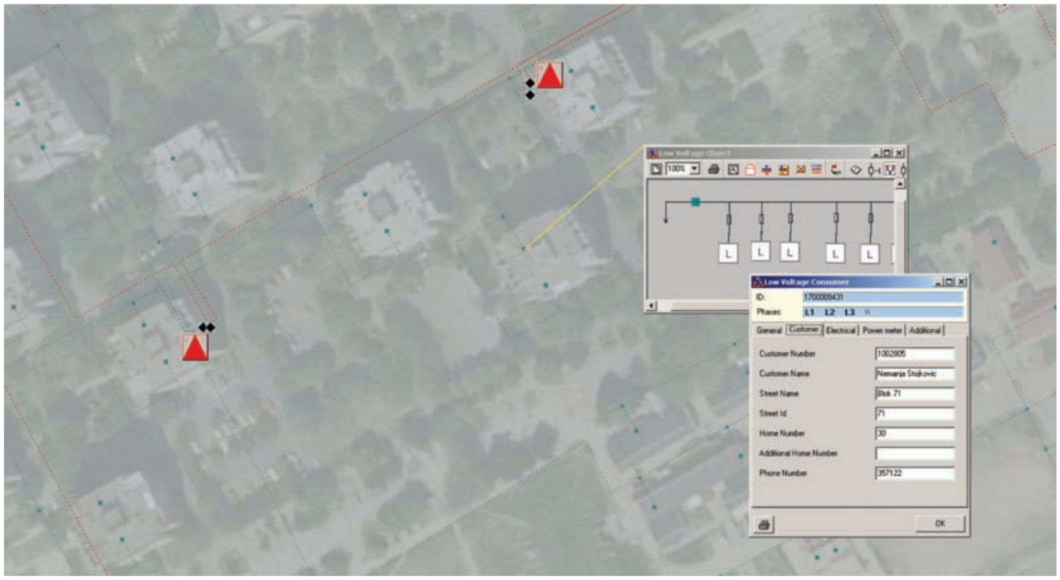


Figure 3
LV network: On the photo background and the example of customer data

3.2 Low-Voltage Network Model

Network model for low-voltage network is specific in the sense that it decouples all LV networks from the MV network. Source of a LV network are LV busbars of a MV/LV transformer. Most calculations in the MV/LV networks are performed only for the radial tree starting from the LV busbar, but the feeding path of the MV network can be used where necessary. Radial and meshed LV network can be analyzed separately and efficiently. The basic data about one radial LV network are:

- data about the root (LV busbar in MV/LV substation, measured consumption on MV/LV transformer, estimated or measured voltage on LV busbars),
- data about topology, parameters and phase information for all network elements,
- data about typical load behavior in every node of the network,
- consumer information,
- data about motors, dispersed generators and capacitor banks

Since LV networks are, in general, three-phase unbalanced (even in utilities where MV network is built as three-phase balanced), Network Model processes phase information and prepare per-phase models of every network element so that unbalanced Load Calibration and Load Flow can be run.

Interface to Metering System is provided to import data about customer consumption.

3.3 Power Applications in Low-Voltage Module

The following DMS power applications are provided for LV Network:

1. Topology Analyzer
2. State Estimation
3. Load flow
4. Performance Indices
5. Energy Losses

6. Fault Calculation
7. Switch and Fuse Capability
8. Relay/Fuse Coordination
9. Motor Start
10. Reliability Analysis
11. Capacitor Placement
12. LV Network Planning

[Content omitted.]

State Estimation

There are following sources of data for State estimation:

- data about load of MV/LV transformers which feed the LV network, whose magnitude is measured seasonally and daily load curve is taken according to dominant type of consumption in the network,
- data about individual consumers in every LV node–consumption type and installed/maximal load, this kind of data can be imported from Metering System if available.
- A type of (three-phase or single-phase) and a connecting phase are known for each load (customer) of a LV network.
- Nominal (peak) current (power), determined on the basis of nominal current of main fuses or on the basis of realized peak active power (metering) which exists at some consumers on a monthly basis, and monthly supplied active energy. At some consumers, there are data on peak reactive power and consumed monthly reactive energy.
- For some consumers (customers) in LV network, representatives of their daily load diagrams and power factors for each type of day (week-day, weekend days, holidays), each season and peak load values in each month throughout a year are known.
- Data on measured energy (power), currents and phase voltages in some SS and with some consumers can also be remotely read by AMR system. Data on their values can be obtained for specific time intervals (e.g. every hour) but not on-line, as it is the case with SCADA system data. It is necessary to consider the possibility of these data, which are of higher quality than the ones on a monthly basis, to be used in state estimation.
- data about the current load of the equivalent consumer as calculated by the State Estimation function in MV network (which was calculated on the basis of SCADA measurements and historical data). In most SS there are data on monthly flow of active energy, and in some on reactive energy as well.

State estimation function estimates the load in every LV node for the given moment, on the basis of these data. The function uses Weighted Least Squares (WLS) algorithm to reconcile (potentially contradicting) information from above-mentioned data sources, where different weighting factors are assigned (by means of function parameterization) to every group of data. The output of this function is the "most probable" loads in every LV node. These loads present input data for Load Flow, Performance Indices and other DMS LV functions.

Since LV networks are, in general, three-phase unbalanced (even in utilities where MV network is built as three-phase balanced), State Estimation takes into account phase information and run separately for each phase.

Load Flow

LV networks can be three-phase balanced, or, in more general case, three-phase unbalanced (one- or two- phase unbalanced being the special case of the latter), for radial or meshed networks. Balanced or unbalanced Load Flow calculation will run depending on type of the network detected by network model. After running the load flow, entire state of the LV network is calculated (voltages, power and current flows, voltage drops, power losses) for every element of the network. The input data for Load Flow calculation are:

- voltages of root LV busbars in substation MV/LV,
- topology and parameters of LV networks,
- loads of all LV nodes (which are results of Load Calibration).

Performance Indices

Performance Indices function produces global indices of considered LV network state, for entire LV network or individual LV feeders:

- Total input current (for transformers, it denoted current on primary and for LV feeder it denotes current at the beginning of the feeder);
- Total input of active and reactive power
- Total consumption of active and reactive power;
- Total losses of active and reactive power of all elements below the selected one;
- Voltage deviation;
- Minimal voltage in absolute and relative units;
- Disbalance of load per each feeder–index of load disbalance of every LV feeder due to load disbalance per phases;
- Disbalance of voltage in nodes of LV network–index of voltage disbalance for nodes (to which consumers are connected) in LV network.
- list of overloaded sections,
- list of nodes with voltage problems,

In addition, the function determines operation problems (violations of operation limits - voltage and current) for the considered network topology and state. The list of violated limitations contains LV sections with load exceeding the rated current with percent amount of load. All violated limitations are displayed on geographical view with highlighting or blinking.

Within this function, the following coloring schemes are available:

- Coloring according to relative load: LV sections are colored in accordance with relative load (current/rated current ratio);
- Coloring according to voltage: LV sections are colored in accordance with relative voltage at their ends and (consumer) nodes in accordance with their relative voltages. Relative voltage is calculated as difference between voltage at the ends of section or consumer node and appropriate nominal voltage;
- Coloring according to voltage drop, LV sections are colored in accordance with voltage drop. Voltage drop is defined as percentage difference between actual voltage and voltage of the source of network (LV busbars in supply SS for LV sections).

Energy Losses and Energy Audit

LV networks contribute for the great part of power losses in the entire power system. By modeling of LV networks and analysis of losses (on the basis of Load Flow results), it is possible to determine main sources of technical losses in the network. This function, for user-selected time period, can analyze one or several selected networks or all LV networks of the area.

The calculation of technical energy losses is done for selected period (a day, a week, a month, from date X to date Y, a year). For every day from the considered period the calculation of energy losses is done in the following way: for every hour within 24 hours load flow calculation is being done, it is assumed that calculated power losses last for an hour and on the basis of that energy losses are calculated in every part of the system. By summing and memorizing these data it is possible to obtain data about energy losses in every selected period and for any part of network.

The calculation of non-technical energy losses is done by deducting technical losses from total losses calculated from metering data for accessable parts of the system. These parts of the system can be the following:

- Supply (HV/MV, MV/MV) substations and transformers,
- MV feeders,
- Distribution (MV/LV) substations and transformers,
- LV feeders.

Fault Calculation

Fault Calculation function calculates LV network state with faults (line to ground fault, line to line fault, line to line to ground fault, phase interruption), as well as complex faults (simultaneous appearance of several short circuits and interruptions).

The calculation of currents and voltages in network with fault is graphically presented, as well as with detailed tabular report.

Switch and Fuse Capability

Function “Switch and Fuse Capability” performs systematic check of all switches and fuses in LV networks. For every individual switch or fuse in the network, the function tests feasibility of the device on the basis of the following criteria:

- whether the device rated current can sustain maximal operating current,
- whether the device rated breaking current can sustain maximal fault current.

Results of these checks are presented in a form of report, as well as in form of tags next to every device on the network diagram.

Relay/Fuse Coordination

Relay/Fuse Coordination function performs the analysis of feasibility of actual settings/ratings of existing relays in the LV network (which are installed mostly in LV transformer bays, if present at all) and fuses which protect LV network feeders, laterals, consumers and/or motors and generators. This function, like in MV network has several modes:

- In Operation mode, an analysis of acting fuses and relays is performed for user-specified location and type of fault.
- In Sensitivity-mode, a check is performed whether the existing relays and fuses can protect against critical faults (minimal currents) in entire LV network.
- In Study-mode (settings and coordination) t/I (time/current) diagrams of all fuses/relays along the path are displayed and analyzed, with possibility to check whether another fuse or other relay settings can improve the operation of protection.

Motor Start

Motor Start function enable analyses of the quasi-dynamic state in LV networks during the start of one or more large LV motors. This function calculates all the voltages and currents in the network during the motor start. Capability of all fuses placed along the path of motor supply is tested, as well as analysis of voltage drops which occur on the analyzed motor(s) as well as in consumption nodes. The results of influence of motor start are presented in form of a report, along with current and voltage diagrams for selected branches/node(s).

Reliability Analysis

Reliability Analysis is being used for analyzing the reliability of the radial distribution network, i.e. for calculation of the annual non-delivered electric energy and other reliability indices for LV network (ENS, SAIDI, SAIFI). In calculation, faults are simulated and the degree of LV feeder automations is considered, as well as possible resupply options.

The function is being used for reliability analysis of the actual network configuration, as well as reliability analysis of the network configuration in Study case.

Capacitor Placement

Capacitor Placement function determines optimal number and locations of new capacitor banks in the LV network for the purposes of power losses reduction.

Installation of capacitor banks has special importance in LV networks containing a lot of electromotor drives. The function determines the optimal engagement of existing and/or newly installed capacitor banks that have the capability of regulated operation (off/on switching or changeable capacity) during selected period of analysis.

Network Planning

Network planning functionality is applied on LV network as well. Complex scenarios for LV network reconstruction or development are easily created and applied on the network for technical and cost/benefit analysis.

G EASYPOWER RESPONSE

Tool Description

EasyPower V9.0 for Windows. The EasyPower product family delivers a full lineup of powerful Windows®-based electrical software tools for intelligently designing, analyzing, and monitoring electrical power systems. With the fastest processing speeds on the market, EasyPower power system software delivers instantaneous, accurate results to help you make more intelligent decisions every day.

EasyPower is used by many utilities throughout the nation to model and analyze their complex secondary network models. EasyPower is designed for Windows XP, Vista, and Windows 7.0, and runs on both 32 and 64 bit Windows versions.

Because this is a limited space format, only a limited overview of some of the programs used for utility LV networks will be provided. For more complete technical information see www.easypower.com.

Network Solution Capability

EasyPower uses the latest in sparse matrix solutions designed by IEEE Fellow William Tinney for all algorithms. EasyPower's sparse solutions combined with meticulous attention to programming detail provide the fastest solution algorithms available. Interactive results such as opening or closing a breaker, or changing a transformer tap are instantaneous no matter how large the system, allowing the user to see how the system responds on the one-line without waiting. EasyPower solves both tightly and weakly coupled, meshed networks and has no bus count limitations, although the software is sold with a choice of 100, 300, 1000, or Unlimited bus versions.

EasyPower's Power Flow engine uses the proven CI Power Flow method. The CI method has no high R/X limitations and handles all distributed generation requirements. The current power flow engine is a balanced engine with no limitations for any LV network solution. See http://www.easypower.com/ep_powerflow.php for more information.

EasyPower's Short Circuit engine provides ANSI Standard and IEC solutions. Three-phase, SLG, DLG, LL, Line-end, and Line-out fault types are provided. Results can be viewed on the one-line or by reports in phase or sequence components. A full multi-phase unbalanced engine has been developed and tested for release in spring of 2010. See http://www.easypower.com/ep_ansi_shortcircuit.php for more information.

EasyPower's Short Circuit engine also provides the latest in Arc Flash Hazard calculations using the IEEE-1584, and NFPA 70E calculation methods. EasyPower's integrated time step method provides the most accurate calculations available and is the only IEEE-1584 method that can successfully solve complex meshed network solutions with multiple relays and network protectors tripping throughout the solution. See http://www.easypower.com/ep_arcflash.php for more information.

EasyPower's Protective Device Coordination program (PowerProtector) allows easy graphical protective device settings for all phase overcurrent devices including relays, fuses and network protectors. Though EasyPower's extensive manufacturers' library includes equipment dated back into the 1940's, ESA will gladly provide library entry and modeling for devices not found in the library. See http://www.easypower.com/ep_powerprotector.php for more information.

EasyPower's SmartPDC (used in conjunction with PowerProtector) provides automated protective device coordination for radial systems and allows customizable rule settings so selectivity can be tailored to the user's protection requirements. Detailed output reports document the reasons for all setting selections and provide a detailed record of existing and recommended settings. State of the art graphical output provides all the details required for insuring a reliable system. See http://www.easypower.com/ep_smartpdc.php for more information.

Unbalanced Network Solution Capability—2010

A full multi-phase unbalanced engine has been developed and tested for release in spring of 2010. Please call for more details.

Solution Capabilities for Highly Meshed Networks

EasyPower provides the following solution capabilities for highly meshed networks.

- Power Flow
- Short Circuit–ANSI Standard and IEC
- Arc Flash Hazard
- Harmonics
- Dynamic Stability
- Protective Device Coordination
- SmartPDC–Automated Protective Device Coordination for radial systems
- SmartDesign–Automated LV design per NEC requirements

Please see http://www.easypower.com/easypower_family.php for more information on the full line of EasyPower software products.

EasyPower also provides custom solutions to utilities that have specific needs or interface requirements. Please feel free to call us if you have any needs that are not addressed in this introduction.

Data Sources

EasyPower uses a proprietary database for speed requirements. However, we allow user access for exporting in CSV, Excel, and DXF formats. We are also open to writing any interface solutions that utilities might require such as GIS, Multispeak, CIM, etc.

Load Modeling Capability

EasyPower's Power Flow engine has multiple load models including:

- Constant kVA (P + jQ)
- Constant Impedance
- Constant Current
- Constant KW +j I (motor model)

All loads are scalable both in the individual load model and globally. Loads can also be scaled interactively while in the Power Flow focus during analysis. In addition, EasyPower allows SCADA or load billing information to be "read in" via file for near real time power flow analysis. EasyPower V9.0 provides balanced network solutions. A full multi-phase unbalanced network engine has been completed and is scheduled for release in the spring of 2010.

ESA also works with vendors to integrate SCADA system measured data into real-time analysis with the fastest power flow solution available. If real time critical power flow analysis and "what-if's" are important, please contact us for these capabilities.

H ASPEN DISTRIVIEW RESPONSE

ASPEN Response

Tool Description	
– Name	ASPEN DistriView
– Version	Version 8
Network Solution Capability	
– Radial only	No. Software can handle both radial and mesh networks
– Weakly meshed networks	Yes
– Highly meshed networks	Yes
– High R/X limitations, if any	Yes
– Size limitations, if any	32,000 nodes
– Other limitations	None
Circuit Model	
– Positive-sequence power flow only	No. Software can handle 2- and single-phase network with unbalanced loads and shunts
– Symmetrical component impedance model (Z1, Z0)	Yes
– Full unbalanced 3-phase impedances	Yes, e.g., untransposed lines
– Higher phase orders, double circuits, etc.	Yes, double circuit
– Per unit model vs. actual values	Computation is done in phase domain in physical units
– Single voltage level vs. multiple voltage levels	Software can handle any number of voltage levels
Solution Capabilities for Highly meshed Networks	
– Power Flow	Yes, for balanced and unbalanced networks
– Short Circuit	Yes, for balanced and unbalanced networks. Power flow solution can be used as starting voltage profile
– Harmonics	Yes. Harmonic load flow, frequency scan, computation of various indices, etc.
– State Estimation	No
– Electromagnetic Transients	No
– Distributed generation	Yes, Multiple synchronous machines and induction machines are allowed
– Machine dynamics	No
– Inverters dynamics	No
– Renewable (variable) generation	Will be available in an update within a year

(Continued)

Data Sources	
– Database (type, whether proprietary or open, etc.)	No
– Text files	Yes. Format is open
– Proprietary binary files	Yes
– CIM interface	No
– Multispeak interface	Yes
– GIS interface	No
– Export for other programs	No
Load Modeling Capability	
– Constant kVA (P + jQ)	Yes. Each load can have constant-KVA, constant-Z and constant-I components
– Constant Impedance	Yes
– Constant Current	Yes
– Other voltage-dependent models (CVR, etc.)	No
– 1-, 2-, and 3-phase loads	Yes. Loads can be line-to-line or line-to-neutral
– MV/LV transformer connections	Yes
– Load allocation from connected kVA	Yes
– Load allocation from kWh billing	Yes. Also allocation by REA method and by line length
– Capability for incorporating AMI data and SCADA data	No
– Capability for loadshapes (daily, weekly, yearly, etc.)	No
– State estimation capability	None

SKM POWER TOOLS RESPONSE

The following information was supplied by Kevin Jiminez, Duke Energy. Jiminez uses DAPPER to perform power flow studies on a system consisting of 400 transformers feeding into four networks. Before that, the Principal Investigator was unaware that DAPPER had network solution capability. This information comes from the user's manual.

Solution Method

PTW models either an Exact (Iterative) or Approximate Solution. Upon creating a new Project, PTW selects the Exact (Iterative) Solution method by default. It is recommended that you run the Study using the Exact (Iterative) Solution method first. This is because the solution method usually converges on most power systems. In the unlikely event that the steady-state load flow solution does not converge, you should re-run the Study using the Approximate Solution method. If it does not converge, a message in the Study Message dialog box will notify you of the problem.

When the Approximate Solution method is selected, PTW temporarily converts all loads to constant impedance type characteristics, making these system losses smaller than if constant kVA type loads were modeled. An output report is then written, and data is sent to the database. Although it is an approximate solution (since the load characteristic is approximated), this solution method may help to identify the reasons for the non-convergence.

Utility Impedance

If you select the Utility Impedance check box, PTW uses the three-phase short circuit capacity to calculate an equivalent positive sequence impedance. The voltage drop at the swing bus is calculated, given the total power supplied by the swing bus generator and this positive sequence impedance. It is reported separately in the Load Flow Report. Upon opening a new Project, the PTW does not model the system equivalent impedance by default. This means the voltage at the swing bus is equal to the voltage of the swing bus generator, which is set by default to 1 pu voltage at 0°.

The following information was found on the SKM Power Tools web site. Note shaded paragraph below.

DAPPER Studies

DAPPER is an integrated set of modules for Three-Phase Power System Design and Analysis including rigorous load flow and voltage drop calculations, impact motor starting, traditional fault analysis, demand and design load analysis, feeder, raceway and transformer sizing, and panel, MCC, and switchboard schedule specification.

Benefits:

- Generate better designs by comparing alternatives quickly.
- Improve accuracy with DAPPER's rigorous solution methods.
- Save time by sharing a common project database and interface.
- Improve consistency with standard design libraries.
- Design safer systems by comparing calculations with short circuit and continuous ratings.
- Communicate designs effectively with presentation quality graphics, reports, and equipment schedules.

Load Flow/Voltage Drop

With DAPPER, users can calculate the voltage drop on each feeder and transformer branch, voltage on each bus, projected power flow, and losses in the power system.

This program may be used for conventional voltage drop analysis, loss analysis, power factor studies, capacitor placement, long-line charging effects, impact loading for motor starting studies, generator sizing, and for cogeneration analysis.

With DAPPER, a single load flow program models loop and radial power systems. Double precision sparse matrix current injection solutions are used for faster, more accurate convergence. This allows for better modeling of ill-conditioned systems.

Features:

- Models radial, loop, and multiple independent systems.
- Models utility and generator equivalent impedance calculated from short circuit duty.
- Models up to 50 utilities/swing bus generators.
- Models up to 400 regulated and unregulated co-generators.
- User definable per unit driving voltage at each utility and swing bus generator.
- Models transformer primary and secondary taps and off nominal rated voltages.
- Full transmission line modeling with built in line parameter calculators.
- Models any combination of motor and non-motor loads with global and/or local load factors.
- Models any combination of constant kVA, constant impedance and constant current loads.
- Reports bus voltage, voltage angle, and voltage drop at each bus.
- Reports branch voltage drop, power flow in kW, kVAR, kVA, Amps and power factor.
- Reports branch loss in kW, kVAR, kVA, and total system losses.
- User definable report criteria for bus and branch voltage drops.
- Percentage voltage drops based on system voltage per ANSI standards.
- Double precision calculations improve solution accuracy.
- Rapid solution convergence.
- Suitable for impact motor starting, capacitor placement and power factor studies.
- Load flow results validated to match with benchmark calculations and IEEE examples.

Comprehensive Fault Analysis

The DAPPER Comprehensive Fault Analysis program provides a network solution of three-phase, single-line to ground, line-to line, and double line to ground fault currents; RMS momentary fault currents; asymmetrical fault duties at three, five, and eight cycles; the positive, negative, and zero sequence impedance values between each fault location, and contributions from utilities, generators, and motors. At each fault location, the direction, X/R, and magnitude of fault currents are reported, thus providing a clear view of the conditions that exist during the fault.

Features:

- Symmetrical and Asymmetrical values reported at 1/2, 3, 5, and 8 cycles.
- Asymmetrical values reported at user selected fault time.
- Asymmetrical values reported as peak or RMS values.
- Models two and three winding transformer taps, phase shift, and off nominal rated voltages.
- Asymmetrical exponential DC decay is based on X/R to each contribution.
- Reports Thevenin equivalent impedance and X/R at the faulted bus.
- Detailed and summary reporting options.
- Reports bus voltages and branch flows throughout the system for each faulted bus.
- Reports phase or sequence current and voltage.
- Reports ground return current for double line to ground faults.
- Models transformer and generator neutral grounding impedances.

Demand Load Analysis

Features:

- Reports Connected, Demand, and Design loads.
- All load calculations account for individual load power factors.
- Automatically creates input load data for Load Flow and Voltage Drop Studies.
- Automatically creates loads for sizing feeders and transformers.
- System demand loads calculated using methods recognized by the NEC.
- Automatically tracks largest motor fed by each bus to meet NEC requirements.
- Automatic compliance with NEC and local codes for multi-level load diversity.
- Sensitivity studies, future load growth studies and load diversity studies by scaling load factors globally.
- "What if" analysis of loading conditions, i.e. light loading versus normal loading, or winter versus summer loading.
- Meet utility company requirements for providing a load summary by load type for connected, demand, and design loads at each utility bus.
- Generate sufficient information for sizing feeders, transformers, and other elements of the power system.

Feeder and Transformer Sizing

DAPPER will size feeder cables, ground wires, raceways, bus ducts, duct banks and transformers throughout the power system to the load requirements calculated by the Demand Load Analysis program.

Feeders are selected to meet user-defined criteria for conductor material, voltage level, insulation type, and environmental conditions. Transformer primary and secondary feeders are sized to the transformer full load as specified by the user. Feeders and transformers may be included, excluded or evaluated in the sizing study.

Features:

- AWG, Bus Duct, ACSR, or metric sizes may be used.
- Feeders and transformers with "Do Not Size" are evaluated for capacity.
- Feeder libraries permit user to include metric sizes and ampacity.
- Transformers can be sized to Demand or Design load.

Load Schedules

The DAPPER Load Schedule module provides detailed documentation of load fed through Panels, Motor Control Centers (MCCs) and Switchboards. Input is simplified through the use of libraries and copy and paste functions. The schedules can be displayed, printed, and exported in a variety of different formats.

Features:

- Schedules are automatically updated with available short circuit values and sub-feed totals.
- Switch board schedules are automatically generated from connected branch loads.
- MCC schedules can reference a default design library for automatic selection of feeder and raceway sizes, or the complete cable library for more detailed specification.

ELECTRIC POWER RESEARCH INSTITUTE

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute Inc., (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

1017690

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com