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Coordinating Worldwide Distribution Planning Model Development via an Open Source Modeling Platform

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SUMMARY
The grid of the future is projected to change in many ways from its present state. This will require new modeling and simulation tools for distribution planners. There is an opportunity to accelerate the development of new tools in the power industry through the use of open source software. This is especially applicable for software that can be used for research and development and as a foundation for a variety of applications. The open source model is ideal for an organization like EPRI with a public benefit mission and a collaborative model for developing and applying new technology. The Distribution System Simulator (DSS) software that had been developed previously as an advanced tool for evaluating the integration of distributed resources was an ideal candidate for release as open source, creating the opportunity for ongoing collaboration around the world on development of new modeling approaches, evaluation approaches, optimization methods and planning guidelines. This has the tremendous advantage of being readily available for university applications so that students can use state-of-the-art tools and do their research on real world systems. It allows a focus of their research on advancing the state of the art rather than repeating the development of fundamental tools that has been done before. The resulting experience, developments and learning can then be implemented in commercial tools throughout the industry. It was a very exciting proposition and completely aligned with the EPRI model.

KEYWORDS
Open-source software, Distribution Models, Distribution Planning, Collaboration

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THE OPENDSS PROGRAM

The OpenDSS is a comprehensive electrical power system simulation tool primarly intended for modeling electric utility power distribution systems. It supports nearly all frequency domain (sinusoidal steady-state) analyses commonly performed on electric utility power distribution systems. In addition, it supports many new types of analyses that are designed to meet future needs related to smart grid, grid modernization, and renewable energy research. The OpenDSS tool has been used since 1997 in support of various research and consulting projects requiring distribution system analysis. Many of the features found in the program were originally intended to support the analysis of distributed generation (DG) interconnected to utility distribution systems and that continues to be a common use. Other features support analysis of such things as energy efficiency in power delivery and harmonic current flow. The OpenDSS is designed to be indefinitely expandable so that it can be easily modified to meet the needs of the grid of the future.[1], [2]

While some sort of power flow solution is generally the most common analysis performed with the program, it would not be appropriate to refer to the program as a power flow program. The program's circuit modeling capabilities were derived from a family of harmonic modeling programs. This gives the program exceptional circuit modeling capabilities that makes it well-suited for modeling new grid structures. Although it works in the frequency domain (phasor modeling), its ability to represent electrical circuits rivals that of many electromagnetic transients modeling tools.

The program was one of the first to introduce sequential-time solutions for distribution planning. This capability was designed into the software when it was created so that it would efficiently accommodate this type of analysis. This remains one of its strengths, particularly for the recent interest in modeling solar PV impacts in 1-s intervals. [3]

Another strength of the tool is that it is *scriptable.* This may be done through either text files that can be created on any text editor or the program's COM interface from another program. This feature is critical because it allows the tool to adapt to different needs under user control. It is also an attractive feature for the academic community because it allows students to pursue their research interests with more freedom to explore.

PROGRAM DISTRIBUTION

The OpenDSS software was placed into open source in September 2008 on open-source sharing site Sourceforge.net. Prior to that time, EPRI had used it privately for internal power systems studies of DG interconnections, multi-year planning, distribution efficiency, and impacts of harmonic-producing devices. Others had become familiar with the tool and were requesting that EPRI commercialize the program so they could have access. At the same time, Smart Grid and other grid modernization efforts were growing rapidly and demanding new types of tools. EPRI realized that it would not be able to economically support the varied demands on the tool and decided the option that would return the best value for EPRI member utilities would be to put the tool in the public domain and allow others to use it and help develop it.

The worldwide response to this decision has exceeded all expectations. Figure 1 shows that the number of downloads per month has increased nearly linearly since the program was introduced to open source in 2008, passing 36,000 in July 2015. That is, the number of downloads is actually accelerating.

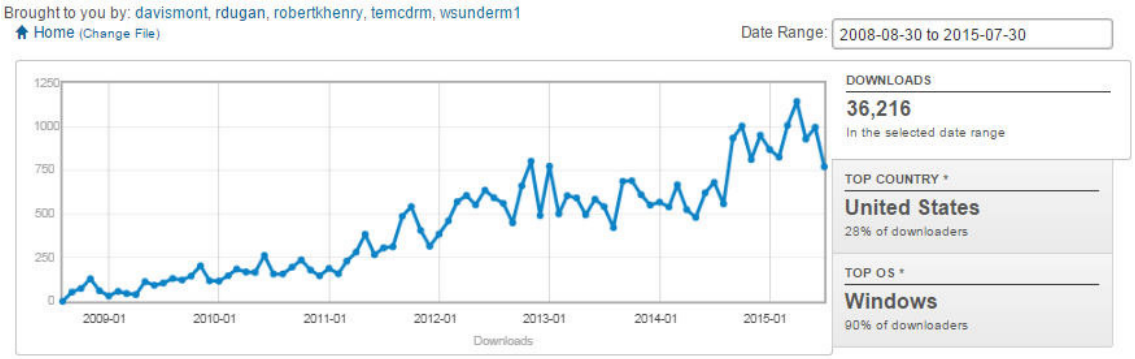

Figure 1. Downloads as of July 30, 2015

Most of the downloads are from university students around the world. Several Masters and Ph.D. projects have been supported by the program. One of the more successful outcomes of making the program open source has been the fostering of collaboration between utilities and universities. When an EPRI utility member hosts an OpenDSS training workshop, EPRI encourages the utility to invite participation from universities they wish to work with. Engineering consultants who supply services to the utilities are also frequently invited.

Figure 2 illustrates the distribution of the program world wide. The US leads in downloads with nearly 10,000 to date. China, Brazil, India, Canada, Taiwan, UK, and Germany have over 1000 downloads each. The next section of this paper will highlight an exceptional contribution from Colombia. Sourceforge.net generally reports in excess of 170 countries with at least one download.

	Country	Android	Linux	Macintosh	Unknown	Windows	Total
1.	United States	0%	1%	3%	6%	63%	9,961
2.	China	1%	2%	1%	5%	64%	2,466
3.	Brazil	0%	4%	0%	0%	82%	2,077
4.	India	1%	2%	0%	1%	72%	1,863
5.	Canada	0%	1%	2%	1%	70%	1,812
6.	Taiwan	0%	0%	0%	0%	76%	1,736
7.	United Kingdom	0%	2%	2%	1%	72%	1,682
8.	Germany	0%	5%	2%	30%	47%	1,396
9.	Spain	1%	6%	0%	10%	42%	746
10.	Italy	0%	3%	3%	0%	60%	724
11.	Australia	1%	4%	4%	0%	53%	650
12.	Colombia	0%	1%	1%	0%	91%	572

Figure 2. Top 12 countries for OpenDSS downloads from Sourceforge.net

COLOMBIA: REAL TIME AND HIL FROM OPENDSS

OpenDSS has opened doors to collaboration in many places in the world where it was admittedly not anticipated by the program's developers and sponsors. However, this illustrates the impact of open-source software. In this section, co-author and Ph. D. candidate Davis Montenegro-Martinez describes the advanced work in real-time simulation and hardware-in-the-loop (HIL) simulation being performed in Bogota. OpenDSS is driven from the National Instruments LabVIEW program for this application.

Graphical User Interfaces (GUI) and interoperability play an important role when simulating the future distribution systems. An approach to complement OpenDSS with these features was developed in DSSim-PC/RT [4]-[6] which are the versions generated to support PC/Real-Time simulation based on OpenDSS. This project is being developed in Colombia by the University of Los Andes in collaboration with the University Joseph Fourier, Grenoble-Alpes in France.

These simulators were developed using the *actor* model to distribute tasks in a multicore environment and to preserve the simulation performance; however, in the Real-Time version, the solver structure of OpenDSS was modified to make it suitable for multithread computing using standard PC architectures. This approach, called A-Diakoptics combines the actor model [7] and Diakoptics [8] to split the system in several subsystems, which can be solved independently using dedicated hardware. Then the partial solutions are collected to find the equivalent solution for the interconnected network. These subsystems are processed independently and the communications between them are done by sending messages, which reduces the memory needed and the inconsistencies present when sharing data using global variables.

With this concept, the simulation times get normalized and modern computing architectures can be exploited in an optimal way for Real-Time purposes. Moreover, by using the actor model as a framework (where everything is considered as an actor), external devices can be integrated with the simulation using standard communication interfaces such as TCP/UDP connections, making it possible to translate phasor data into equivalent analogue signals carrying information about the power system variables, which can then be fed back to the simulation.

As a result, Controller Hardware-In-the-Loop (CHIL) and Power Hardware-In-the-Loop (PHIL) can be performed using OpenDSS as a base platform. [9], [10] Additionally, the A-Diakoptics method has been tested in the PC version and it is expected to be implemented in the source code of OpenDSS to make it available for all OpenDSS users.

Also, other simulation modes such as sequential-time harmonics [11] and several new models have been added to the original code of OpenDSS, expanding the range of applications that can be simulated with OpenDSS to perform smart grid studies.

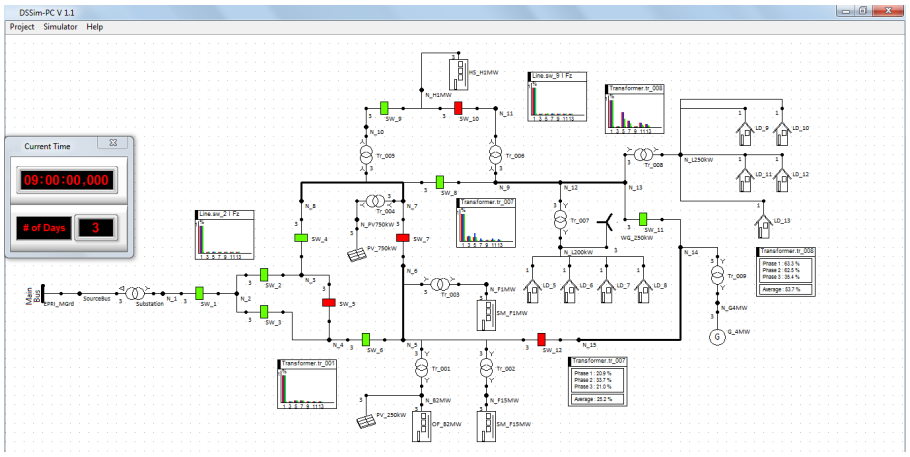

Figure 3. Sequential time harmonics simulation performed using DSSim-PC (University de Los Andes, Colombia)

The DSSim-PC/RT project is one example of several developments inspired by OpenDSS, leading researchers to customize general-purpose tools for specific needs and to contribute to the evolution of open source simulation tools. Figure 3 shows the user interface for sequential-time harmonics simulation performed to evaluate the effect of the *%RL* series property of load models in OpenDSS.

OTHER EXAMPLES OF ADVANCED OPENDSS APPLICATIONS

University Of Manchester (UK): LV Distribution Modeling

(Courtesy of Dr. Luis F. Ochoa with students Alejandro Navarro Esponosa and Andreas Procopiou).

The University of Manchester has been employing OpenDSS to investigate means of controlling voltages on LV distribution systems. Figure 4 illustrates the results of two simulations of a feeder with

extensive solve PV generations with the voltage control implemented in an OLTC-fitted MV/LV transformer.

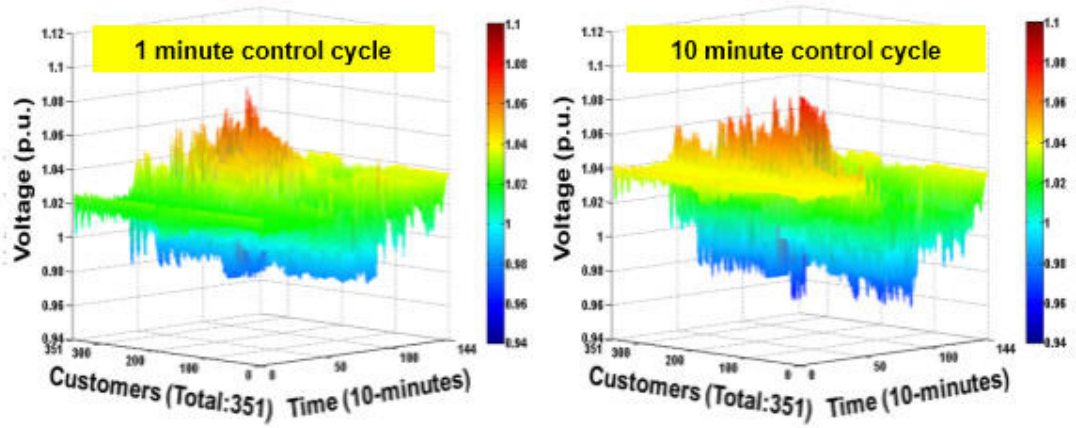

Figure 4. Daily Voltage Profiles of all customers on LV distribution system for different control cycles (U. Manchester, UK)

Dr. Ochoa has become one of the leading users of OpenDSS in Europe and has also conducted training workshops in other parts of the world. He also maintains the following website with extensive OpenDSS training material :
https://www.escholar.manchester.ac.uk/uk-ac-man-scw:229196

University Of Pittsburgh (US): Feeder Modeling with a Web Browser
(Courtesy of Dr. Thomas McDermott, University of Pittsburgh)

Dr. McDermott is a co-developer of the original DSS program. He continues to develop models for the program and has incorporated OpenDSS in research and education. His M.S. level classes incorporate Line Constants and Load Flow methods.

Figure 5 shows output from an application of OpenDSS that is accessed on a web server through a web browser interface. The program was specially modified to run under the Apache server. This work was performed for US utility FirstEnergy Corp. He is actively involved in an EPRI-funded project to implement adaptive voltage regulation for PV inverters in OpenDSS.

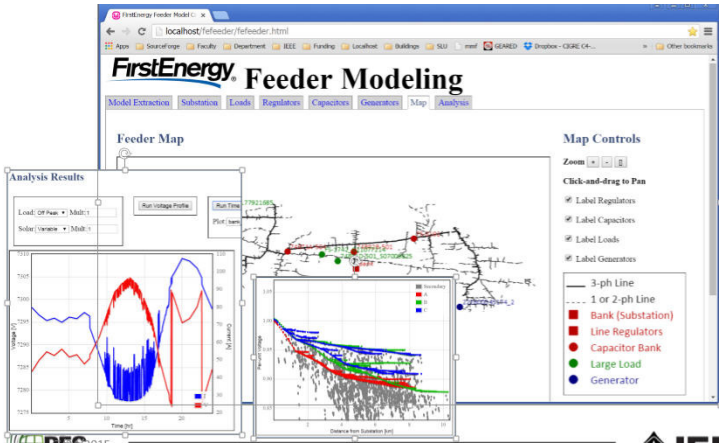

Figure 5. Quasi-static time series simulation of a full feeder model using a web browser (University of Pittsburgh, US).

Computing Distribution Losses in Brazil


ANEEL
AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA

Processos: 48500.002869/2014-98

Assunto: Aprimoramento da metodologia de cálculo de perdas na distribuição regulamentada no Módulo 7 – Cálculo de Perdas na Distribuição do PRODIST.

paulo.radatz
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New method is presented in this report in order to improve losses calculation methodology in the distribution.

ANEXO

A seguir será apresentado um exemplo de um sistema de distribuição hipotético. O
equipamentos utilizados no sistema de distribuição brasileiro e apresentar os resu
modelados os circuitos de média tensão desde o barramento de saída da subestaçã
de média e baixa tensão, compreendendo os seguintes equipamentos existentes na
reguladores de tensão.

O *script* com a linguagem de programação utiliz da pelo programa OpenDSS consta do anexo esta Nota Técnica, assim como os resultados do estudo de fluxo de carga.

1. Dados do circuito

A figura a seguir apresenta a topologia do referido circuito. Destaca-se que se trata de um alimentador de distribuição em 13,8 kV com dois circuitos de baixa tensão associados e dois reguladores de tensão. A carga foi representada pelo modelo ZIP como 50% de potência constante e 50% de impedância constante para a parte ativa, e como 100% de impedância constante para a parte reativa.

Figure 6. Excerpt of regulatory document recommending the use of OpenDSS for loas calculations (Brazil)

EPRI was advised in 2015 that the electric system regulator in Brazil was recommending that utilities use OpenDSS to calculate losses. Figure 6 shows an excerpt from the ANEEL regulatory document. This is another illustration of an unexpected far-reaching impact from releasing OpenDSS to the public.

OTHER INTERESTING APPLICATIONS

Dr. Michael Kleinberg at DNV GL in the US, with Rick Fioravanti and Frederic Dubois, have implemented an extensive energy storage valuation tool, **ESGRID**, based on OpenDSS. OpenDSS is driven from Microsoft Excel, which has proven to be quite capable as a scripting tool.

Gianni Celli, Fabrizio Pilo, et. al., at the University of Cagliari, Italy, have used OpenDSS in conjunction with MATLAB and *ns2* to demonstrate co-simulation of power and ICT networks. (Round Table 5b, CIRED 2013, Stockholm).

Xendee.com : a cloud-based tool for distribution system analysis based on the OpenDSS platform.

CONCLUSIONS

- The open source model for fundamental industry simulation tools can be a great support for ongoing innovation and collaboration around the world.

- Effectiveness of research around the world can be enhanced through sharing of real world case studies and examples, as well as the tools that can be the foundation of the analysis.

- Simulation methods and tools for distribution planning and operations is particularly appropriate for open source tools and sharing of example cases because there is so much innovation and new development needed to support widespread distributed resource integration and also integration with transmission system models and operations.

- The scope of collaboration available is truly international becoming a real accelerator for innovation as demonstrated in the examples cited.

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