

# An Example of Integrating Open Source Modelling Frameworks: The Integration of GIS in PSAT

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**Abstract**—This panel paper presents an example of interaction between different open source projects, namely PSAT and OSGIS. PSAT is a well-known applications for power system analysis, while OSGIS is a suite of tools for Geographical Information System (GIS) drawing, analysis and visualization. The main purpose of the paper is to show that the open-source philosophy is suitable for producing, in a much shorter period of time, surprising and interesting results. In particular, we show an application for visualizing geographical maps of power systems with inclusion of information on electrical quantities (e.g., voltage levels). An example based on the Italian HV transmission system is presented and discussed in detail.

**Index Terms**—Open source software, power system analysis, Geographical Information System (GIS), topological scheme, temperature map.

## I. INTRODUCTION

### A. Motivation

One of the most important advantages of free and open-source software (FOSS) is that it makes possible re-using existing code and merging different software packages into new and less costly applications. FOSS avoids *reinventing the wheel* and, in turn, helps progress. This short paper shows how it is possible to create, with a reduced implementation effort, the integration of a Geographical Information System (GIS) into a power system analysis tool, which is a feature so far provided only by proprietary applications. This paper also shows, using a real-world example, how FOSS promotes collaboration among researchers and practitioners.

### B. Literature Review

The importance of an intuitive and fully informative visualization of power system results has been recognized and was formalized in the early nineties. In [1], the authors specify three guidelines for setting up a good graphical representation of a physical phenomena: (i) natural encoding of information; (ii) task-specific graphics; and (iii) no gratuitous graphics. In [2], [3], two-dimensional contour plots are proposed for the visualization of voltage bus levels with inclusion of the topological information of the network. The contour plot complies with the three guidelines mentioned above. In this paper, the idea of using contour plots proposed in [2] is applied to geographical information systems (GIS).

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In [4]–[9], the contour plot technique is further developed for visualizing a variety of data, such as power flows in transmission lines, locational marginal prices, available transfer capability, contingency analysis, etc. All these references focus on static data visualization and are basically two-dimensional plots. However, a simple animation is provided for visualising the effect of load power variations. The flows are represented by moving arrows in the topological scheme and transmission line and transformer saturation are indicated by means of pie charts. The tool described in [4]–[9] is proprietary software and cannot be customized or freely distributed.

Geographical Information Systems (GIS) are used to *visualise, digitise* and *analyse* data by linking geographic locations to information. Geospatial Data is used for creating maps, assigning data (or extracting “features”, which is the name given to individual geometrical objects) and performing spatial analysis. For this aim, several commercial platforms have developed their own proprietary data format.

The key issues when it comes to handling data and information is the interoperability and interworkability of the geoprocessing technologies: data, systems and services. The Open Geospatial Consortium [10] defines open interfaces and protocols by the OpenGIS Specification [11] to “make complex spatial information and services accessible and useful with all kinds of applications”.

Open Source GIS, also referred to as OSGIS, is used for the many OS projects on GIS applications [12]. For this brief paper, a toolkit of different open-source software applications were used. Relevant applications are OpenJump [13], uDig [14], Quantum GIS [15], PostGIS/PostgreSQL [16], and the geospatial libraries that these platforms are built on [17]. Using the toolkit provided by OSGIS applications allows one to efficiently and quickly achieve interesting results, with quality comparable to commercial applications.

### C. Contributions

In summary, these are the novel contributions of this panel paper.

- 1) To show the ability of open-source projects to merge the knowledge and the experience of very different areas.
- 2) To provide a detailed example of the integration of GIS and power system analysis package based on open source projects.
- 3) To show that the open source approach eases collaboration among researchers.

### D. Paper Organization

The remainder of this paper is organized as follows. Section II describes the basic concepts of GIS. Section III gives

an outline of PSAT and describes the integration with GIS. Section IV presents some examples based on the Italian HV transmission grid. Finally, in Section V, conclusions are duly drawn.

## II. OUTLINES OF GIS

### A. Geospacial Data

Geospacial data is classified into raster and vector data. The main difference is that raster data is basically a pixel-based image, while vector data are defined by coordinates and mathematical functions. Several different format standards exist, and some of them are published and open to the public. The most popular open and human-readable XML encoded formats are the Geographical Markup Language (GML) [18] and the Keyhole Markup Language (KML) [19]. The latter was developed by Google but has since evolved and harmonized with the relevant OGC implementation standards.

### B. GIS and Power Systems

Network operators use GIS for their infrastructure and utilities management and network construction planning. As a part of the the network information system, the geographical data of the network is associated with the database of the utility (see for example Fig. 1). An interface to enterprise resource planning (ERP) software may exist for the organization of the resources. Furthermore, network planners often need the GIS data for simulating future planned network assets. In most cases, these two systems are separated and operate independently. The only link is an identification or location reference in a database table. Recently, the major GIS software houses have been trying to interface power system simulation software. This interface allows only one common and consistent database. For example, a project of EDF Energy and GE Energy for a network planning system comprises of the Smallworld GIS application with an embedded network analysis engine [20].

Thus, a GIS-based power system information platform can provide:

- Geographical, topological and schematic representation.
- Graphical representation of simulation analysis results.
- Cable layout and detailed local area network plan.
- Search and query functions.
- Live information about the network status.

## III. INTEGRATION OF GIS IN PSAT

### A. Outlines of PSAT

The Power System Analysis Toolbox (PSAT) is a MATLAB and GNU/Octave-based toolbox for electric power system analysis [21]. Main features of PSAT are: power flow; continuation power flow; optimal power flow; small signal stability analysis; time domain simulation; Phasor Measurement Unit (PMU) placement; FACTS and wind turbine models; conversion of data files from several formats; export results to EPS, plain text, MS Excel and  $\LaTeX$  files; and interfaces to GAMS and UWPFLOW Programs. PSAT provides also a complete GUI (see Fig. 2) and a one-line diagram editor (see Fig. 3).

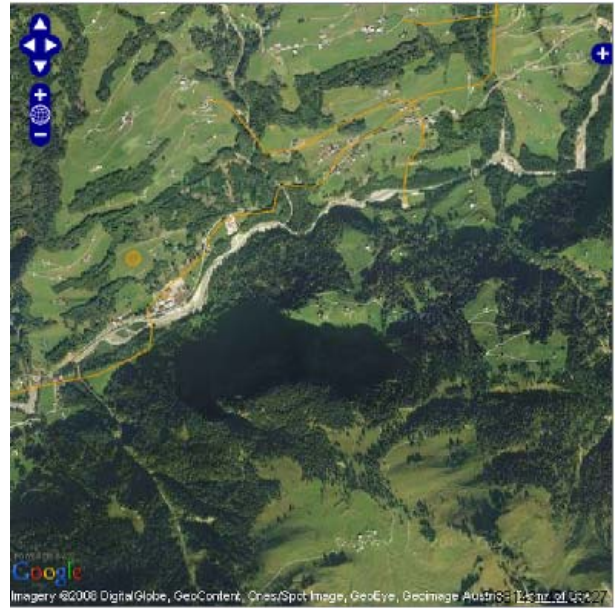


Fig. 1. An example electrical scheme with geographical information in Google Maps. The map represents a distribution system in Austria.

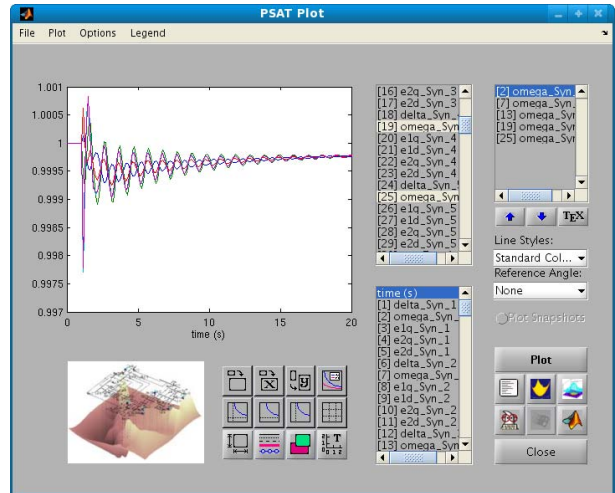


Fig. 2. PSAT GUI for plotting time domain simulation results.

The new version of PSAT, which will be released as version 3, is based on Python [22] and deeply exploits modern concepts of this powerful object-oriented scripting language.

PSAT is able to produce 2D and 3D maps of power systems. Figure 4 is an example of a 2D temperature map where the colors represent a voltage level. The map is built based on the topological scheme provided in the one-line Simulink diagram of Fig. 3. The interested reader can find more details on 2D and 3D visualization and animation that can be obtained with PSAT in [23].

Creating a GIS architecture in MATLAB, although possible in principle, would require a massive programming effort. Creating the interface for introducing the GIS data and defining the structure of the GIS data are not straightforward tasks. Thus, the quickest way to incorporate a GIS system

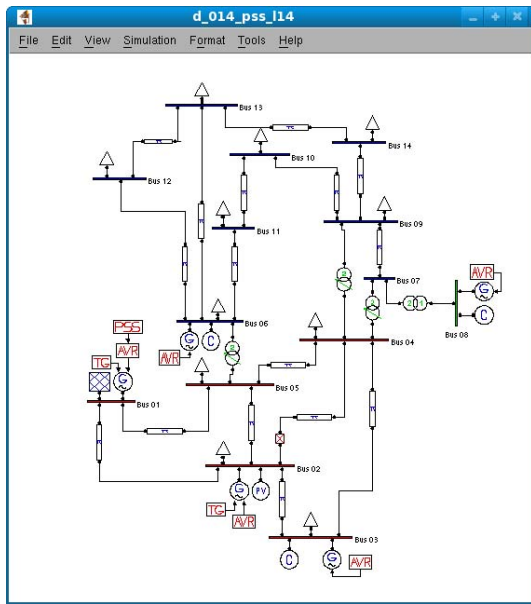


Fig. 3. IEEE 14-bus system drawn using the PSAT Simulink library.

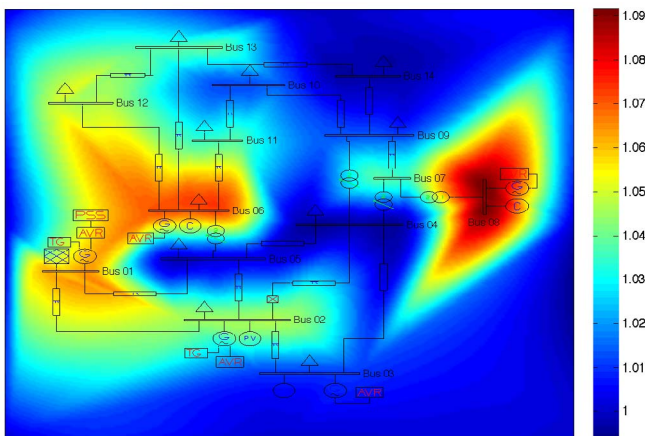


Fig. 4. 2D temperature map of the voltage levels of the power flow solution of the IEEE 14-bus system.

in a program like PSAT is to create the geographical map using an external program and then import the GIS data into PSAT. This way, the programming effort is reduced to the code necessary for importing the data. Clearly, a necessary condition for implementing the bridge between the GIS application (e.g. OpenJump [13]) and PSAT is that the GIS application allows creating user-defined data and that PSAT allows incorporating custom import functions. These requisites are certainly satisfied if the applications are open-source. The remainder of this section describes the steps necessary to create the bridge between the GIS and the power system application.

### B. Definition of custom data in the GIS applications

Buses are referenced in PSAT using unique identification codes (IDs). These IDs must be assigned to their geometrical

representation. For example, in the case of buses, the geometrical representation is a point type primitive.

Lines are identified by the buses with which they are connected. Due to basic geospatial analysis the “from” and “to” bus are assigned to the lines automatically by using the geographical location attribute of their representation. The points of connections are defined using an exact location match. In this way, the resulting topological scheme is realistic and unintentional geometric “touches” are avoided. As a byproduct of geospatial techniques, the length of the transmission lines is computed and automatically assigned to the topological element.

As previously discussed, assigning geographical information to the network topology is obtained by referencing buses with the unambiguous IDs. For the demonstration case presented in this paper, the IDs are the only information needed to link the network topology to electrical data. Other physical data can also be assigned to the topological scheme. For example, assigning line impedances could be used to analyse the impact of different network enlargements.

Open source geospatial libraries are the base of many open-source desktop GIS applications. Since the libraries are distributed as extensible open-source code, one can freely use, access and extend the functionality of these libraries by means of plug-ins or script interfaces (Python, Java, etc.). For the case study presented in this paper, OpenJump and embedded Java code interpreted by BeanShell were used. However, this is just one possible solution. A Python script in QuantumGIS or a Java plug-in in uDig would have worked as well.

OpenJump allows exporting the topological data in GML format, which is a special XML scheme particularly suited for defining GIS [18]. The GML/XML format can be easily exchanged and parsed by other applications. The next step is to parse the XML file containing the GIS data and assign the topological information to each electrical device (basically buses, lines and frontiers).

The current version of PSAT is based on Matlab and this language does not allow easy parsing of XML files. Nevertheless, parsing XML data is rather simple using other languages. For example, Python is a well-known and widely-used scripting language that comes with a huge variety of general-purpose libraries [24], including XML [25]. Python is nowadays mature enough for mathematical analysis (e.g. the libraries NumPy [26] and CVXOPT [27]) and for producing publication-quality figures (e.g. the library Matplotlib [28]).

A new experimental version of PSAT is completely based on Python. This allows easily importing XML files, solving the power flow analysis and, finally, plotting temperature maps that merge topological data and the electrical quantities (e.g. bus voltage magnitudes). A sample case study is described in Section IV.

### C. A brief story of the “making” of this project

The software tool described in this paper is the result of a collaborations between arsenal research, Austria, and University of Castilla-La Mancha, Spain. The authors of this short paper got in touch because of the interest of arsenal



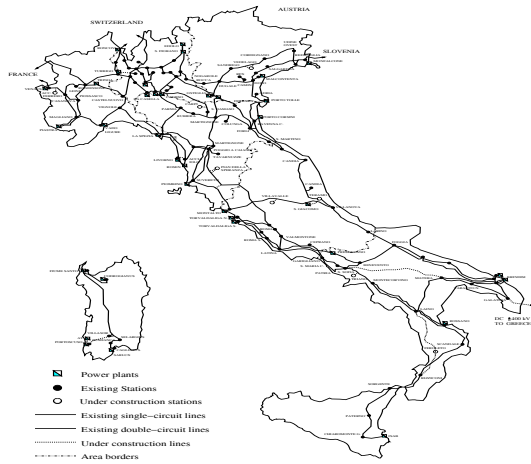


Fig. 5. The Italian HV transmission system.

research in the free software PSAT. This is a clear example of the ability of FOSS to create connections among researchers based on an open and fruitful exchange of experience and knowledge. Surprisingly enough, the authors of this paper have never personally met and have collaborated solely using the Internet.

The interest of arsenal research in PSAT was born within the renewable energy department, which has been developing strategies for voltage control and improving power quality in distribution networks. In particular, over- and under-voltage due to demand and generation of active and reactive power are the main factors of power quality in distribution networks. Thus, the control of the power contribution can be used to increase the share of distributed renewable energy generators.

The implementation of the voltage controller is based on Matlab and is solved using PSAT. Since power system data from network utilities for the simulation comes from commercially-available proprietary software like PowerFactory, the implementation of the complex control algorithms required extensive validation and debugging during development. For this purpose, arsenal research has developed a filter for converting the power system data from PowerFactory to enable simulation in PSAT.

Further development is devoted to integrating the developed voltage control strategies in a GIS-based simulation platform for planning and evaluating the location of distributed generators according to technical (like network interconnection), economic and environmental criteria.

#### IV. EXAMPLE

Figure 5 depicts the Italian 400 kV transmission grid. The mainland system has been drawn in OpenJump and then imported into the Python-based version of PSAT. The results are shown in Figs. 6 and 7, which illustrate a temperature map of bus voltage magnitude levels of a power flow solution. In the maps, generators are represented as blue squares while loads are indicated by green triangles. Bus names can also be displayed (see Fig. 7).

The procedure for generating the topological scheme is as follows. The first step is to acquire and generate the

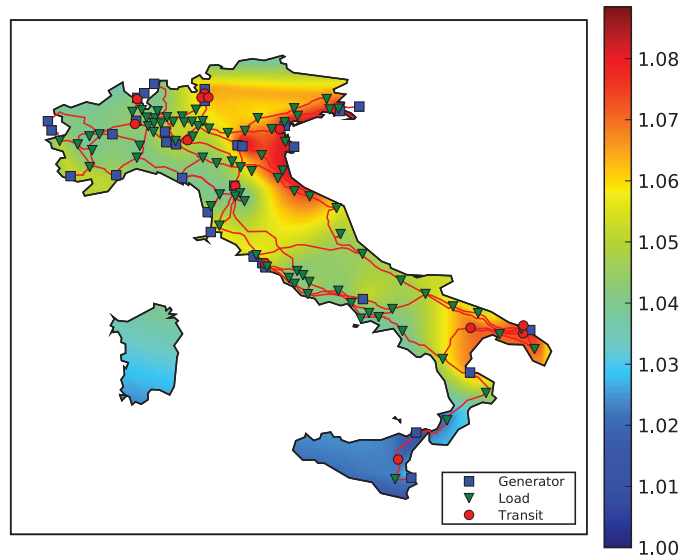


Fig. 6. Bus voltage magnitude map for the Italian HV transmission system.

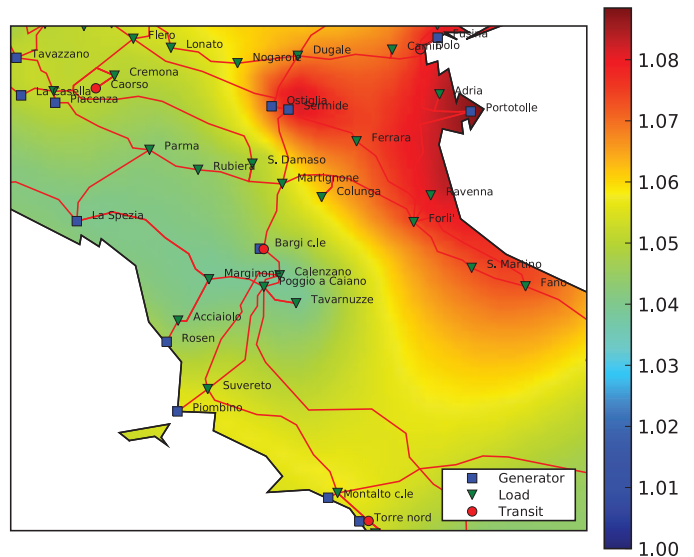


Fig. 7. Bus voltage magnitude map for the Italian HV transmission system, detail of the center-north.

geographical information as a data set for the GIS platform. The picture of the geographical layout of the Italian Grid Fig. 5 was georeferenced with the help of QuantumGIS to generate the spatial representation of the buses and lines. Then, the bus connections of the lines and the length were analysed. Finally a GML file was generated. This file holds the geospatial features and attributes of the Italian HV grid.

The maps of Figs. 6 and 7 have been obtained using the Matplotlib library [28], which allows automatically clipping the map using the border paths. Observe that the quality of the resulting map is comparable if not even better than that obtained using Matlab (see Fig. 4). An entire family of maps can be also generated by importing PSAT results into the JML file once the power flow analysis has been solved in PSAT. Figure 8 shows an example of the possibilities of the JML

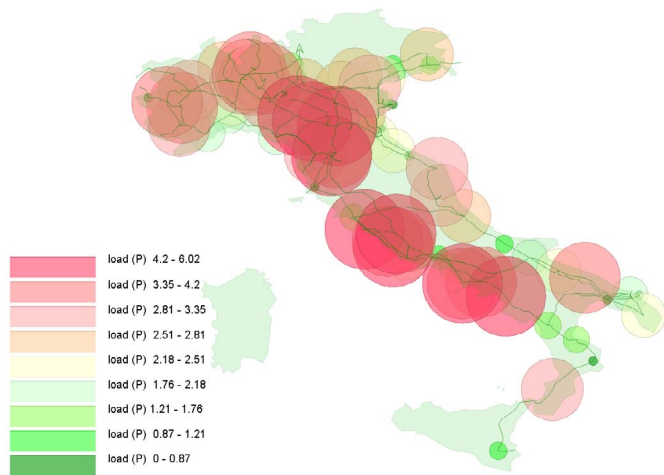


Fig. 8. Load active power visualization for the Italian grid obtained using the JML-OSGIS tools. Values in the legend are in p.u.

format and GIS visualization tools.

Of course, several other maps, using different color palettes and/or electrical quantities, could be drawn. For example, the next step could be applying DEM (Digital Elevation Models) techniques and generating 3D terrain based on the voltage temperature map shown in Fig. 6. However, the goal of this paper is not to show the possibilities offered by Python and OSGIS graphical libraries, but rather to demonstrate that including GIS in a power system analysis package is not only possible but also relatively easy.

## V. CONCLUSIONS

This panel paper shows how the open source philosophy makes possible creating in a quick and transparent way interfaces among applications from very different areas. In particular, we show how to incorporate a simple but extensible GIS system in a package for power system analysis. We believe that the results are promising. This simple project can be used as a paradigmatic example of the power of free and open source software.

## REFERENCES

- [1] P. M. Mahadev and R. D. Christie, "Envisioning PowerSystem Data: Concepts and a Prototype System State Representation," *IEEE Transactions on Power Systems*, vol. 8, no. 3, pp. 1084–1090, Aug. 1993.
- [2] J. D. Weber and T. J. Overbye, "Voltage Contours for Power System Visualization," *IEEE Transactions on Power Systems*, vol. 15, no. 1, pp. 404–409, Feb. 2000.
- [3] T. J. Overbye, D. A. Wiegmann, A. M. Rich, and Y. Sun, "Human Factors Aspects of Power System Voltage Contour Visualizations," *IEEE Transactions on Power Systems*, vol. 18, no. 1, pp. 76–82, Feb. 2003.
- [4] T. J. Overbye, J. D. Weber, and K. J. Patten, "Analysis and Visualization of Market Power in Electric Power Systems," in *Proceedings of the 32th Hawaii International Conference on System Sciences*, Hawaii, 1999.
- [5] T. J. Overbye and J. D. Weber, "Visualizing Power System Data," in *Proceedings of the 33th Hawaii International Conference on System Sciences*, Hawaii, 2000.
- [6] —, "Visualizing the Electric Grid," *IEEE Spectrum*, pp. 52–58, Feb. 2001.
- [7] R. P. Klump and J. D. Weber, "Real-Time Data Retrieval and New Visualization Techniques for the Energy Industry," in *Proceedings of the 35th Hawaii International Conference on System Sciences*, Hawaii, 2002.

- [8] R. Klump, W. Wu, and G. Dooley, "Displaying Aggregate Data, Interrelated Quantities, and Data Trends in Electric Power Systems," in *Proceedings of the 36th Hawaii International Conference on System Sciences*, Hawaii, 2003.
- [9] Y. Sun and T. J. Overbye, "Visualizations for Power System Contingency Analysis Data," *IEEE Transactions on Power Systems*, vol. 19, no. 4, pp. 1859–1866, Nov. 2004.
- [10] "Open Geospatial Consortium," available at <http://www.opengeospatial.org>.
- [11] "OpenGIS® Standards and Specifications," available at <http://www.opengeospatial.org/standards>.
- [12] G. E. Sherman, *Desktop GIS: Mapping the Planet with Open Source Tools*. Pragmatic Programmers, November 2008. [Online]. Available: <http://www.desktopgisbook.com>
- [13] "OpenJUMP - The free, Java based and open source Geographic Information System for the World," available at <http://openjump.org>.
- [14] "uDig - User-friendly Desktop Internet GIS," available at <http://udig.refractor.net>.
- [15] "Quantum GIS (QGIS) - user friendly Open Source Geographic Information System," available at <http://www.qgis.org/>.
- [16] "PostGIS," available at <http://postgis.refractor.net>.
- [17] "The Open Source Geospatial Foundation," available at <http://www.osgeo.org>.
- [18] "Geography Markup Language (GML)," available at <http://www.opengeospatial.org/standards/gml>.
- [19] "KML Documentation," available at <http://code.google.com/apis/kml/documentation>.
- [20] B. D'Albertanson and D. Hawkins, "An integrated MV distributed generation connection planning tool," *SmartGrids for Distribution, 2008. IET-CIRED. CIRED Seminar*, June 2008.
- [21] F. Milano, "An Open Source Power System Analysis Toolbox," *IEEE Transactions on Power Systems*, vol. 20, no. 3, pp. 1199–1206, Aug. 2005.
- [22] "Python Programming Language," available at <http://www.python.org>.
- [23] F. Milano, "Three-Dimensional Visualization and Animation for Power Systems Analysis," *Electric Power System Research*, 2008, under review.
- [24] "The Python Standard Library," available at <http://docs.python.org/library>.
- [25] C. A. Jones and F. L. Drake Jr., *Python & XML*. Sebastopol, California: O'Reilly, 2001.
- [26] "NumPy," available at <http://numpy.scipy.org>.
- [27] "CVXOPT: A Python Package for Convex Optimization," available at <http://abel.ee.ucla.edu/cvxopt>.
- [28] "Matplotlib," available at <http://matplotlib.sourceforge.net>.



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