The Experience of PSAT (Power System Analysis Toolbox) as a Free and Open Source Software for Power System Education and Research

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Abstract

This paper describes the assessment of a free and open source software tool for power system analysis and modeling, namely Power System Analysis Toolbox (PSAT). PSAT is currently used in several Universities for undergraduate and graduate courses and research. Several applications of PSAT as an educational and research tool are discussed in this paper. The paper also describes the PSAT Web forum, which provides support to students and researchers all around the world. Finally, the paper presents and discusses the results of a survey on PSAT filled out by the members of the PSAT forum and PSAT users.

Key Words

Power system analysis, open-source software, Internet, Matlab, GNU Octave, power system simulation.

I. INTRODUCTION

Power system courses deal with complex physical phenomena and detailed mathematical models [1]. The complexity of mathematical models often deviate students focus from understanding the underlying physical phenomena. Furthermore, the computational burden of power system analysis is cumbersome even for small networks, especially if dynamic models are involved. As a result, educational power system software has become a fundamental teaching tool because it helps students to assimilate theoretical issues through graphic visualization of results and user-friendly interfaces.

Traditionally, most available power system software packages are commercial products that can only be used by acquiring costly licenses. This drastically limits education and research, particularly in developing nations. In contrast, the deployment of Free and Open Source Software (FOSS) emerges as an alternative platform to distribute an educational and research tool which can be obtained by anyone around the world, and seamlessly creates a community of users/learners that interact and collaborate with each other.

An underlying reason behind the success of a variety of FOSS projects (see for example the Linux, Perl and LaTeX experiences) is the freedom of the users of the software as well as the spirit of collaboration between them. If applied to the power system academic community, the FOSS approach allows the deployment of tools suitable for education and research, and at the same time to create a community of learners [2].

Remarkable efforts have been made by the academic community to provide educational software for teaching power system topics. However, most available tools do not fully apply the FOSS rules and present at least one of the following deficiencies: a lack of wide distribution of the software, access to the source code of the software, a community of users, a comprehensive documentation and the distribution of the software with the GPL license [3].

Some educational software packages, e.g. the Power Education Toolbox (PET) [4], have the major drawback of being closed, i.e. the source code cannot be changed or modified. The lack of flexibility is a major limitation for class instructors and motivated students that wish to explore and make enhancements to the learning tool. Thus, the nature of commercial tools limits the learning process of the students, and imposes a limitation for researchers that need to modify the source code for their own purposes.

Educational software such as the Power Analysis Toolbox (PAT) [5] and the Power System Analysis and Design Environment (PSADE) [6] are not widely distributed. These software packages are only available for students from the institution where the tool was created and very few students from any other institution may have access to them. Consequently, the lack of a wide distribution also has the drawback of a small number of users of the software. If the number is small, finding errors in the program is quite difficult and, more importantly, the creation of a community of learners and collaborators is infeasible.

The educational computer packages mentioned above, and other tools such as UW-PFLOW [7], PST [8], and MATPOWER [9], are not distributed under the General Public License (GPL) [3]. The lack of a GPL restricts the freedom of the users to modify, enhance and redistribute a program that they have modified.

This paper presents authors' and users' experience in the development and usage of the Power System Analysis Toolbox (PSAT) [10], a Free and Open Source Software (FOSS). PSAT is currently used in several Universities all around the world [11]. Statistics on users' feedback, collected on the Web forum dedicated to PSAT, are also presented in this paper. This paper extends and complete the technical notes presented at the 2nd panel session on Open Source Software at the IEEE PES General Meeting 2007 [12].

To the knowledge of the authors, there are currently only two active FOSS projects for power systems: PSAT and InterPSS [13]. While PSAT has been designed to provide a tool suitable for research and education, InterPSS is oriented to consultant activities and power industry applications. The documentation of this software as of September 2007 is rather limited, making it unsuitable for education. Therefore, PSAT is unique in the sense that is the only tool whose main focus is to support education and research.

The remainder of this paper is organized as follows: Section II presents practical and pedagogical strategies for the development of PSAT. Section III describes the PSAT Web forum. In Section III-C we present the results of the user survey. Section IV describes several applications of PSAT as didactic and research tool all around the world. A sample class activity involving PSAT is described in Section V. In Section VI conclusions are drawn.

II. Pedagogical Features of PSAT

The desired features of pedagogical software and free and open source software are discussed in this section. Afterward, we show how PSAT merges the features of both educational and free and open source software. The pedagogical features implemented in the development of PSAT as an undergraduate teaching tool and as a graduate research-oriented tool are also discussed in this section.

A. Features of pedagogical software

Software for educational purposes should be user-friendly and reliable. In particular, software for power system education should contain a user interface that allows drawing one-line diagrams, displays results and plots time domain simulations.

Most commercial software for power system analysis presents the features described above (see for example PSS/E [14]). However, commercial software has two main drawbacks: it needs a costly license and it is typically very difficult (if not impossible) to modify models and/or algorithms provided with the software.

The first drawback limits the diffusion of commercial software in developing countries, while the second issue imposes a severe limitation to the software development by Ph.D. students and researchers.

B. Features of FOSS

In contrast to proprietary software, free and open source software provides the user with the freedom of reading, copying, and modifying the source code. FOSS also allows redistributing the modified code, with the only condition that the resulting program must also be distributed as free and open source software [3].

Despite initial skepticism shown by commercial software companies, a huge number of FOSS projects have been developed and improved thanks to the cooperation of thousands of users. Some FOSS projects have also obtained worldwide success (see for example the Linux, Perl and LaTeX experiences).

If applied to the power system academic community, the FOSS approach allows to deploy tools that are suitable for education and research and, at the same time, the creation of a community of learners [2].

From the educational point of view FOSS projects typically have the drawback of being barely understood by an undergraduate student. Even for Ph.D. students to be familiar with the details of large C++ or Java projects typically requires a lot of time, which should be better dedicated to their research topics.

C. Features of pedagogical FOSS

An education oriented FOSS should merge the positive features of educational software and open source philosophy. Educational free and open source software should have a reasonably user-friendly interface and should be written in a simple and high-level programming language (e.g. Matlab [15] or GNU Octave [16]).

Educational software should develop the learning process and the curiosity of the student. Furthermore, only if the code is open the student can explore all the software features. Finally, the students are motivated to embrace the idea that knowledge should be free and available to everyone [2].

D. PSAT, an example of educational FOSS

PSAT is a Matlab-based FOSS for electric power system simulation and analysis. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces and a SIMULINK-based library provides a user-friendly tool for network design. PSAT is beyond the main scope of this paper. For interested readers, an in-depth description of all features of PSAT can be found in [10] and [11]. A discussion on the usage of PSAT as a Virtual Laboratory is described in [17]. Finally, the Appendix depicts how users can access the source code and the documentation of PSAT.

In the authors' experience, PSAT leads to an improvement of the students' learning process in several ways. First, PSAT appears user-friendly to the students because it is based on MATLAB, which is typically used their undergraduate courses. The students can familiarize themselves with the algorithms not just by using the program, but also by reading and understanding the code. Furthermore, the educator and the students can modify the algorithms implemented in PSAT and eventually add custom features. Finally, PSAT runs on Linux and GNU Octave. Thus, there is no need for an expensive license to set up a laboratory using PSAT. This property is particularly relevant in developing countries where the students may not have access to proprietary software.

III. THE PSAT FORUM

PSAT has been freely distributed on the Internet since November 2002. The original idea was to share a free and open source MATLAB-based software package for power system analysis. Then, a public web forum about PSAT was created on August 2003 on Yahoo!® Groups.

A. Activities of the Forum

The PSAT Forum activities can be categorized as follows: user support, test case repository, and community portal.

1) User support: The main activity of the PSAT Forum is to give user support to all users worldwide. User support is provided by replying to messages posted on the PSAT Forum. Typically, all messages receive a reply. The support provided by the forum is not limited to explain details of the program or collect bug reports. Forum moderators clarify doubts, give suggestions, and also help users to solve specific research issues.

2) Test case repository: In the PSAT Forum there is a dedicated area where test power system networks (e.g. IEEE test cases) are provided to the members in the PSAT data format. Users can also post their own test cases and make them available to other members. The test system database is an excellent source for students of power system courses at any level because several networks that are proposed in common text books can be found in the Forum [18]–[21]. The students can change the configuration of those networks and analyze the effects of the changes. This clearly enhances the student learning process.

3) Community portal: The PSAT forum also works as a community portal for member interaction. The spirit of collaboration in the PSAT Forum is quite uncommon in the conservative power system community. The Forum also makes getting contacts that can make possible research and professional collaborations.

B. User Feedback

With more than 1300 members and more than 5200 posted messages in four years, the PSAT web forum proves that a FOSS can become popular among students of power system courses all around the world. Furthermore, the fact that students subscribe to the forum and post messages about their doubts on simulations and power system issues is an implicit and clear proof of the usefulness of PSAT and its forum. A further discussion on this topic and on frequently asked questions (FAQ) of the Forum can be found in [17].

C. PSAT Survey

This section discusses the updated results (to September 2007) of a survey that was proposed to the members of the PSAT Forum. The text of the survey is available on the PSAT forum. For the sake of completeness, the survey is also reported in the Appendix.

The job distribution of the members of the PSAT forum is depicted in Table I. Note that the majority of the PSAT users are Ph.D. students. Nevertheless, the percentage of researchers, professors, and practitioners is also relevant. Observe also that the percentage of undergraduate students is very low. This fact was expected because undergraduate students typically use PSAT for an assignment and rely on the teaching assistant (TA) and/or the professor to solve their doubts about the program.

Survey statistics are depicted in Fig. 1.

Section A of the survey investigates how users found PSAT and the users' impressions of the software and the PSAT Forum. The results show that almost all of the PSAT users found out about the software through the Internet (see poll A.1). This is mainly thanks to the diffusion of PSAT through University web pages (e.g. University of Waterloo, Canada, and University of Castilla - La Mancha, Spain). The responses to poll A.2 show that up to 45% of the users decided to adopt PSAT because it is distributed as a FOSS, while another 36% of the users decided to use the software because of its features. Poll A.3 asks about reasons users subscribed to the PSAT Forum. As expected, about 44% of the users subscribed to the forum to obtain help with use of the software. However, an interesting statistic is that 34% of the users subscribed to the forum to discuss power systems and about 21% subscribed to give feedback on the program. This is clear evidence that the PSAT Forum has lead to the creation of a community of learners that share their experience in power systems. Note that this is a unique community in the conservative power engineering field. Finally, note that about 67% of the users prefer using PSAT over other power system software packages because it is free and open source (see poll A.4).

Section B of the survey aims to understand how PSAT has been utilized and what has been its impact on the users work. The replies to polls B.1 and B.2 show that about 43% use PSAT for research; among these about 33% use standard routines and sample data files provided with PSAT, while 24% create their own routines and 20% create their own models. Poll B.3 determine the feature of PSAT that has most improved the learning processes of the students. Statistics show that the documentation is the most important source of aid in the learning process with about 30% of the replies, while the PSAT Forum and user-friendliness of the program are ranked with about 23% and 20%, respectively. Finally, observe that about 47% of the users stated that PSAT has been crucial to their research because they did not have access to any other power system software (see poll B.4). This statistic shows one of the most important contributions of PSAT as a research tool.

Finally, polls in Section C address how users can contribute to PSAT improvement and development. Observe that the user feedback can be quite effective due to the open source nature of PSAT. Poll C.1 shows that users have an extremely positive view of FOSS projects, with almost 86% incidence. This result confirms that users find FOSS very useful because they have the freedom to modify the code. Poll C.2 provides useful information on the kinds of models and routines that users would like to see implemented in PSAT. Poll C.3 shows that a relevant percentage of users (about 31%) feel involved in PSAT development simply because it is an open source project. Poll C.4 shows that the documentation should include a very detailed description of how to modify the program and implement a new Simulink model translation tool.

IV. Teaching and Research Applications of PSAT

Figure 2 depicts the diffusion of PSAT around the world. Observe that, because it is free of charge, the diffusion of PSAT is open to industrialized as well as developing countries.

In most cases, as revealed by the survey in Section III-C, users are graduate students using PSAT for their research. However, a relevant percentage of users are also professors or researchers making use of PSAT for education or research purposes.

This section provides an overview on the use of PSAT in universities and companies all around the world. The aim of this overview is to show the versatility of PSAT and to prove the advantages that FOSS can offer to the power system community.

All cases discussed in this section are documented by recommendation letters available at

`www.uclm.es/area/gsee/Web/Federico/archive/psat_references.pdf`.

- *University of Castilla - La Mancha (UCLM), Spain*: PSAT is used in a variety of undergraduate and graduate courses as well as for developing final undergraduate projects. The students have the possibility of interacting with the main developer of PSAT and are asked to develop new features and/or models. PSAT is also the main tool for studying voltage stability constrained OPF (see for example [22]). A further discussion on the use of PSAT at UCLM can be found in [17].
- *University of Waterloo, Canada*: PSAT is used in the assignments of the graduate course E&CE 664 “Power System Computer Applications”. The aim of the assignments is to study the IEEE 14-bus test system and find saddle-node, limit-induced and Hopf bifurcations. The simulations required are power flow analysis, continuation power flow analysis, small signal stability analysis, and time domain simulations.
- *University of Maryland, USA*: The main features that have been utilized at this

University are nonlinear power system models provided by PSAT. The research is to detect and predict power system instabilities through proper signals obtained by nonlinear analysis. Some results that were obtained using PSAT are reported in [23].

- *Rensselaer Polytechnic Institute (RPI)*, USA: PSAT has been used in the undergraduate course EPOW 4010, "Power Engineering Fundamentals" to enhance student learning through computer-based assignments. PSAT was adopted because students quickly learn to use it and because of their positive feedback for the program.
- *University of New South Wales, Australia* and *University of Kocaeli, Turkey*: PSAT is used for both teaching and research. For research, dynamic FACTS models incorporated in PSAT are used as a starting point to develop innovative controllers.
- *Universidad Campinas (Unicamp), Brazil*: In this University, PSAT is used for teaching and research. In particular, two Ph.D. students provided a variety of FACTS models that are currently included in the most recent version of PSAT. Results obtained using these models and PSAT are presented in [24].
- *University of Genoa, Italy*: PSAT has been adopted as the main tool for power system analysis by students working on their final project. In particular, the transient and voltage stability characteristics of a generation plant in Cernavoda, Rumania have been studied.
- *Universidad San Carlos de Guatemala (USCG), Guatemala* and *Universidad Centroamericana José Simeón Cañas, El Salvador*: The adoption of PSAT in these Universities is mainly due to the fact the PSAT is distributed free of charge. PSAT has allowed undergraduate students to develop basic power flow and dynamic analysis without the limiting of demo versions of commercial tools. A further discussion on the use of PSAT at USCG can be found in [17].
- *University of Ljubljana, Slovenia* and *Indian Institute of Technology Roorkee, India*: PSAT has been adopted for its suitability for teaching purposes. For research

purposes, PSAT has been found to be a convenient platform as it allows the user to freely develop and include custom models, which is usually not straightforward with commercial software packages.

- *Nanjing Automation Research Institute, China*: This is an interesting example of usage of PSAT in a company. The toolbox has been adopted because it is free and easy to use. PSAT is used for training new employees and for fast prototyping of new models.
- *National Institute of Applied Sciences and Technology, Tunisian Republic*: The main application of PSAT is the development of detailed electro-mechanical models of induction generators for wind turbines.
- *Asian Institute of Technology, Thailand*: The features of PSAT that have been utilized at this University are the modules for various types of analytical studies (particularly FACTS).
- *Indian Institute of Technology, Kanpur, India*: PSAT is used to study new solutions with FACTS for wind power applications.
- *Federal University of Rio de Janeiro*: PSAT is being used by Ph.D. students for small signal stability analysis considering uncertainties.

V. A Sample Class Activity for Undergraduate Teaching

PSAT can be used to exemplify the topics covered in the textbooks recommended for power system analysis undergraduate, and graduate courses (e.g. [18], [19], [21], [25]). This can be done by designing computer-based class or laboratory activities. In the authors' experience, lab activities stimulate the students' interest in power system analysis [17]. After attending the lab, it is not uncommon that students start designing test systems and experiments on their own.

In this section, we present a class activity to accompany the study of power flow analysis, small-signal stability analysis, and time domain simulation. The activity is suitable for a senior year or a first graduate course on power system stability and control. We use the 9-bus dynamic originally presented in [26], and currently included in the IEEE dynamic system benchmark repository [27].

The class activity is focused on reproducing static and dynamic results of the 9-bus system. The student has to set up the one-line diagram of the network and its controllers using the PSAT-Simulink library. The resulting scheme is depicted in Fig. 3. The Simulink model can be also used to display power flow results (see Fig. 3). Figure 4 shows the eigenvalue loci of the system at the initial equilibrium point. Generator rotor angles and speeds for the time domain simulation are shown in Figs. 5 and 6, respectively. Observe that in the benchmark models, the rotor speed is measured in rad/s, while in PSAT the unit is p.u. This subtle difference implies taking particular care in setting up the parameters of generator, turbine governor, and PSS models. It is also relevant to note that the eigenvalues are similar but not exactly the same as those given in [27] because regulator models currently implemented in PSAT are not exactly the same as the ones used in [27]. Therefore, the student work does not simply consist in copying passively system data, but to adjust *cum grano salis* PSAT models so that they best fit the benchmark guidelines. In graduate courses students are required to modify AVR models available in PSAT, so that they correspond exactly to the models used in [27]. Observe that this class activity can be done only thanks to the open source nature of PSAT.

VI. Conclusions

The paper has presented the authors' experience with PSAT, a free and open source software package for teaching power system analysis and the research experience of several PSAT users.

A variety of real-case PSAT-based experiences in teaching and research have been discussed. The results of a Web-based survey on PSAT have been also presented. The survey reveals the great potential of open source software for improving the student learning process, as well as stimulating engineering practitioners feedback.

The spirit of collaboration within the PSAT project has also led to the creation of a one-of-a-kind community of learners, uncommon to the conservative field of electric power systems engineering.

Future work will concentrate on improving PSAT, based on the results obtained from the survey, and making it increasingly reliable.

VII. Acknowledgments

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Appendix

This appendix depicts the survey that has been proposed to PSAT users. The survey is available at:

`http://tech.groups.yahoo.com/group/psatforum/`

Questionnaire about PSAT

0. What is your job?

- Undergraduate student.
- Master student or Ph.D. candidate.
- Professor or researcher.
- Professional or practitioner in the field of power systems.
- Other (specify. . .).

A. *About you and PSAT.*

A.1. How did you found out about PSAT?

- By looking for a power system software package on the Internet.
- From a friend or a senior student who told me about PSAT.

- A professor introduced me to PSAT.
- I read about PSAT on a paper.
- Other (specify…).

A.2. Why did you decide to use PSAT?

- A professor imposed me to use PSAT.
- I liked the features of PSAT.
- Just because PSAT is open source.
- I had no other available software.
- Other (specify…).

A.3. Why did you subscribe to the PSAT Forum?

- I thought I could get some help.
- To give a feedback on the program.
- To discuss about power systems.
- Actually, I did not subscribe.
- Other (specify…).

A.4. Compared to other software packages, what do you think about PSAT?

- I prefer PSAT because it is open source.
- I prefer other tools, because PSAT is open source and thus not reliable.
- PSAT has limited features.
- I cannot compare because I have used only PSAT.
- Other (specify…).

B. *How did PSAT help you?*

B.1. What have you used PSAT for?

- For an assignment of an undergraduate course.
- For an assignment of a graduate course.
- For my project/thesis.
- For research.
- Other (specify…).

B.2. How have you used PSAT?

- I used standard routines and sample data files.
- I used standard routines and created my custom data files.
- I created my custom models.
- I created my custom routines.
- Other (specify…).

B.3. What features of PSAT have helped you to improve your learning process?

- PSAT is intuitive and easy to use.
- PSAT has a user-friendly interface.
- The PSAT forum helped me.
- The PSAT documentation helped me.
- Other (specify...).

B.4. How was the role of PSAT for your course, project or research?

- Fundamental, because I did not have access to other software.
- Stimulating, because it is open source.
- I used PSAT only to compare results obtained with other software.
- I looked at PSAT only to get ideas.
- Other (specify...).

C. *How can you help PSAT?*

C.1. What is your feeling about open source projects?

- Great. I can open and modify the source code as I like.
- It is useful just for people with a high programming skill.
- Indifferent.
- Bad. I do not trust ”free” software.
- Other (specify...).

C.2. What feature of PSAT would you like to be improved, added or changed?

- A specific algorithm (specify: PF, OPF, etc.).
- A specific model (specify: load model, AVR, etc.).
- The GUI (specify: window appearance, Simulink library, etc.).
- The documentation (specify...).
- The Web forum (specify...).
- Other (specify...).

C.3. How would you contribute to PSAT?

- I feel involved in the PSAT development because it is an open source project.
- I would like to contribute but it is too difficult.
- I would like to, but I do not have time.
- I am not a programmer, but if I find a bug I will post a message on the Forum.
- Other (specify...).

C.4. What would you change in PSAT to feel more involved in its development?

- The documentation should explain better how to modify and/or change PSAT.

- If I could use Simulink to create new models, I would contribute.
- The structure of PSAT should be more modular (e.g. like a Java project).
- I would like to help, but I need to be guided by the PSAT maintainer.
- Other (specify...).

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TABLE I

JOBS OF PSAT USERS

Job	Percentage (%)
Undergraduate student	5
Master student or Ph.D. candidate	58
Professor or researcher	15
Professional or practitioner	22
Other	0

List of Figures

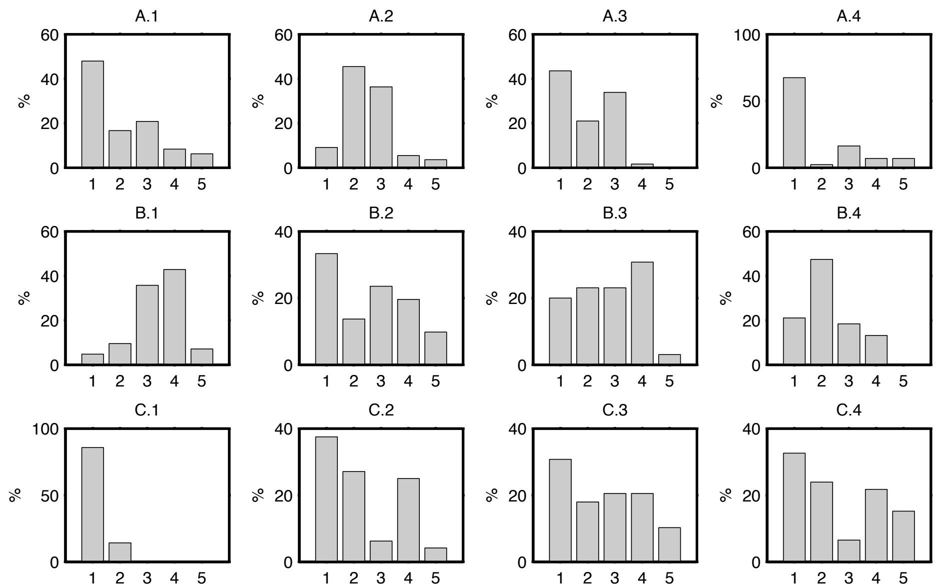

Fig. 1. Statistics for the survey on PSAT (Updated on September 2007)

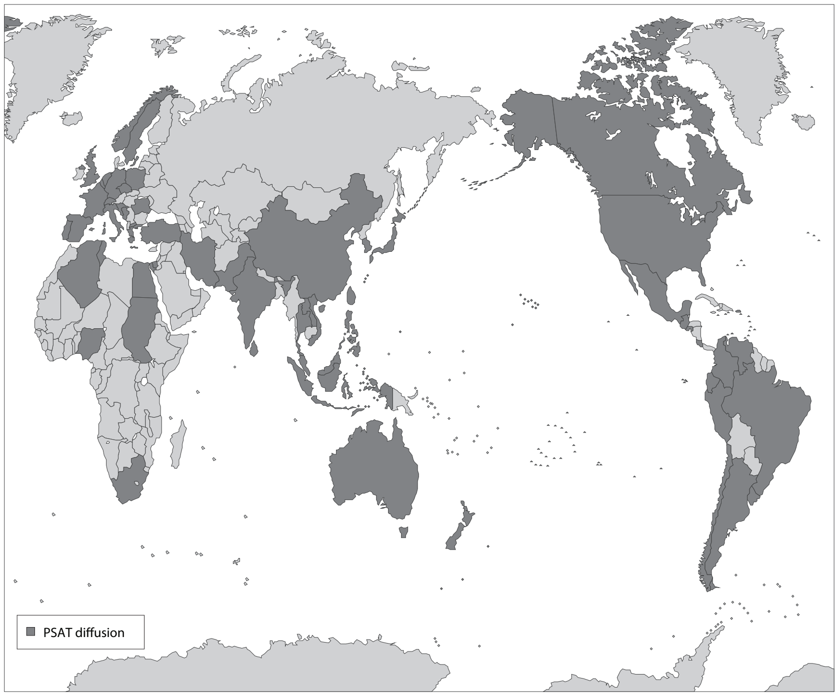

Fig. 2. Worldwide diffusion of PSAT. Shaded regions indicate where PSAT is being used.

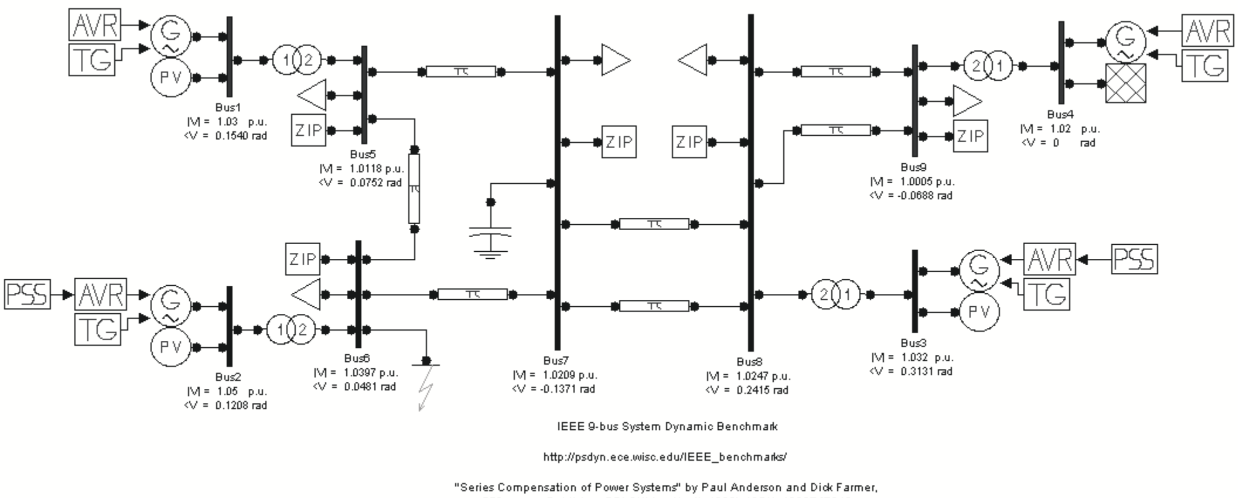

Fig. 3. PSAT-Simulink one-line diagram of the 9-bus system.

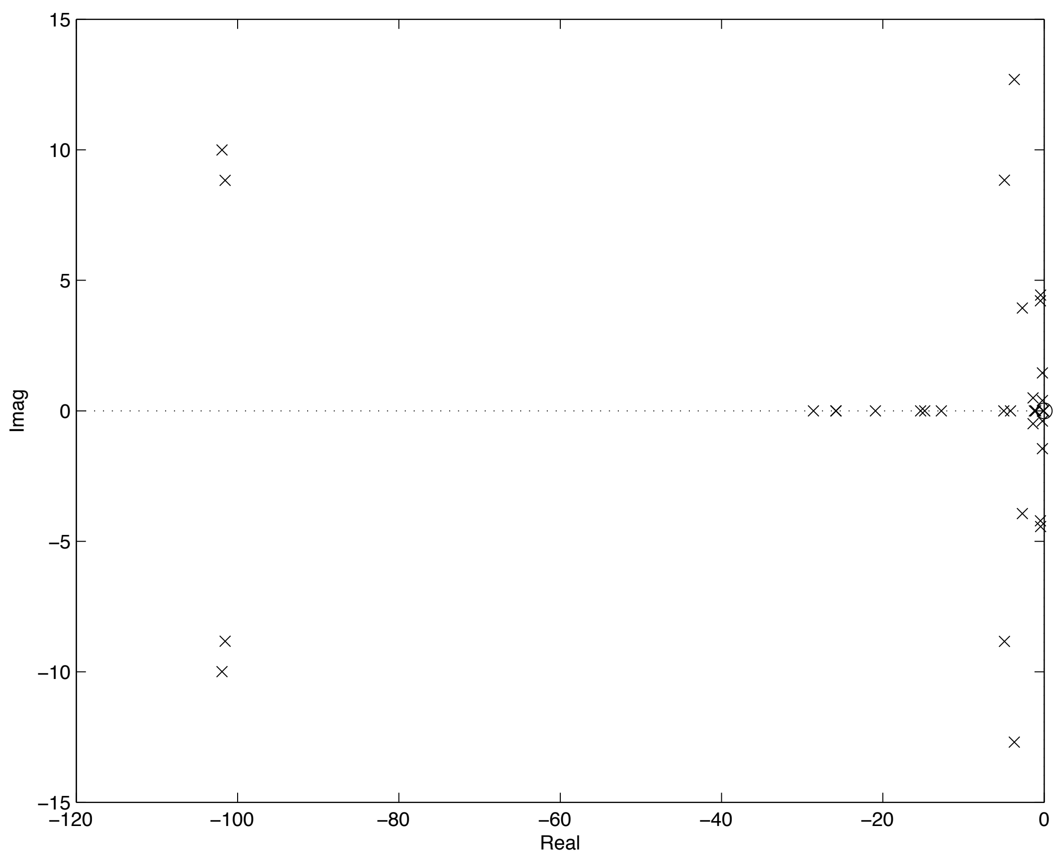

Fig. 4. Eigenvalue loci for the 9-bus system.

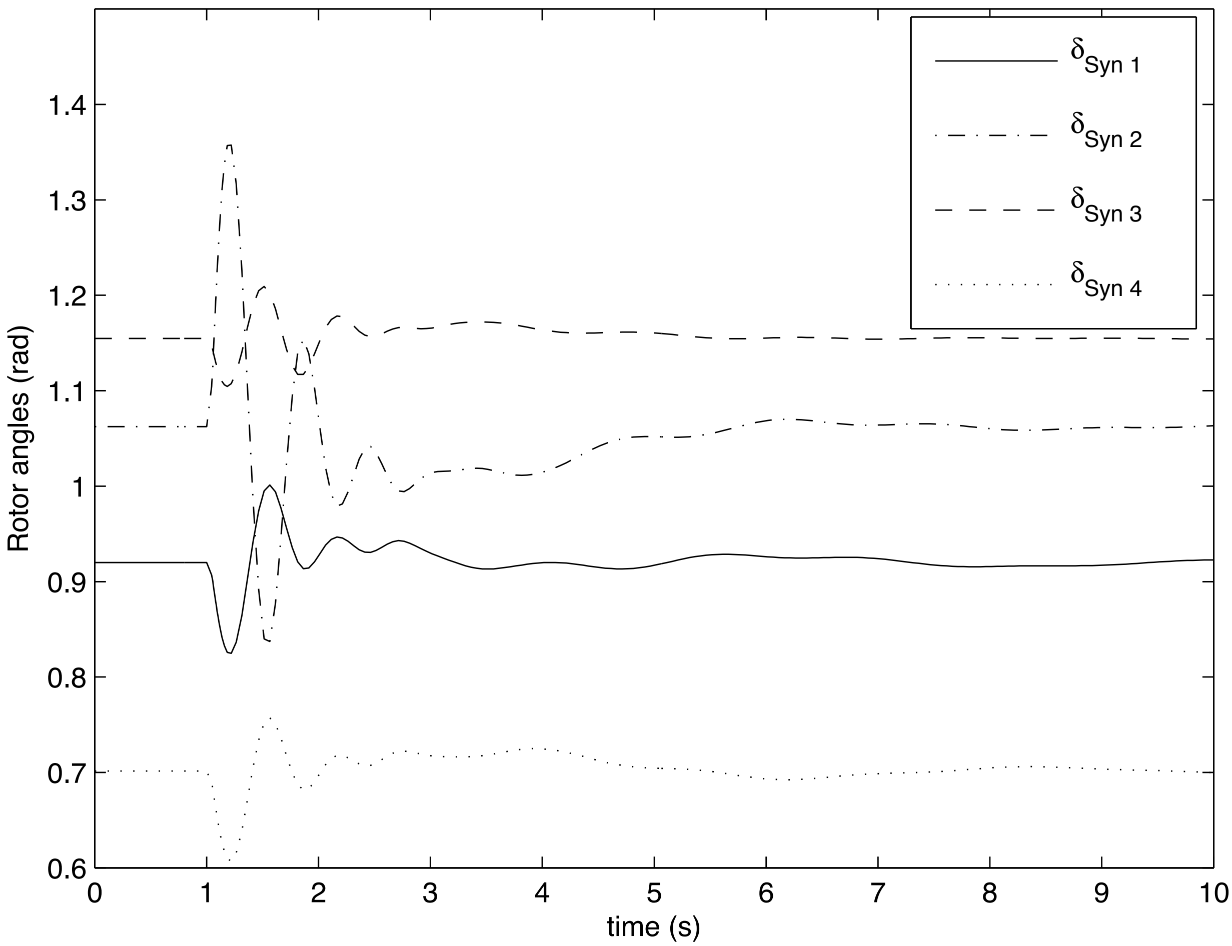

Fig. 5. Rotor angle plot for the 9-bus system.

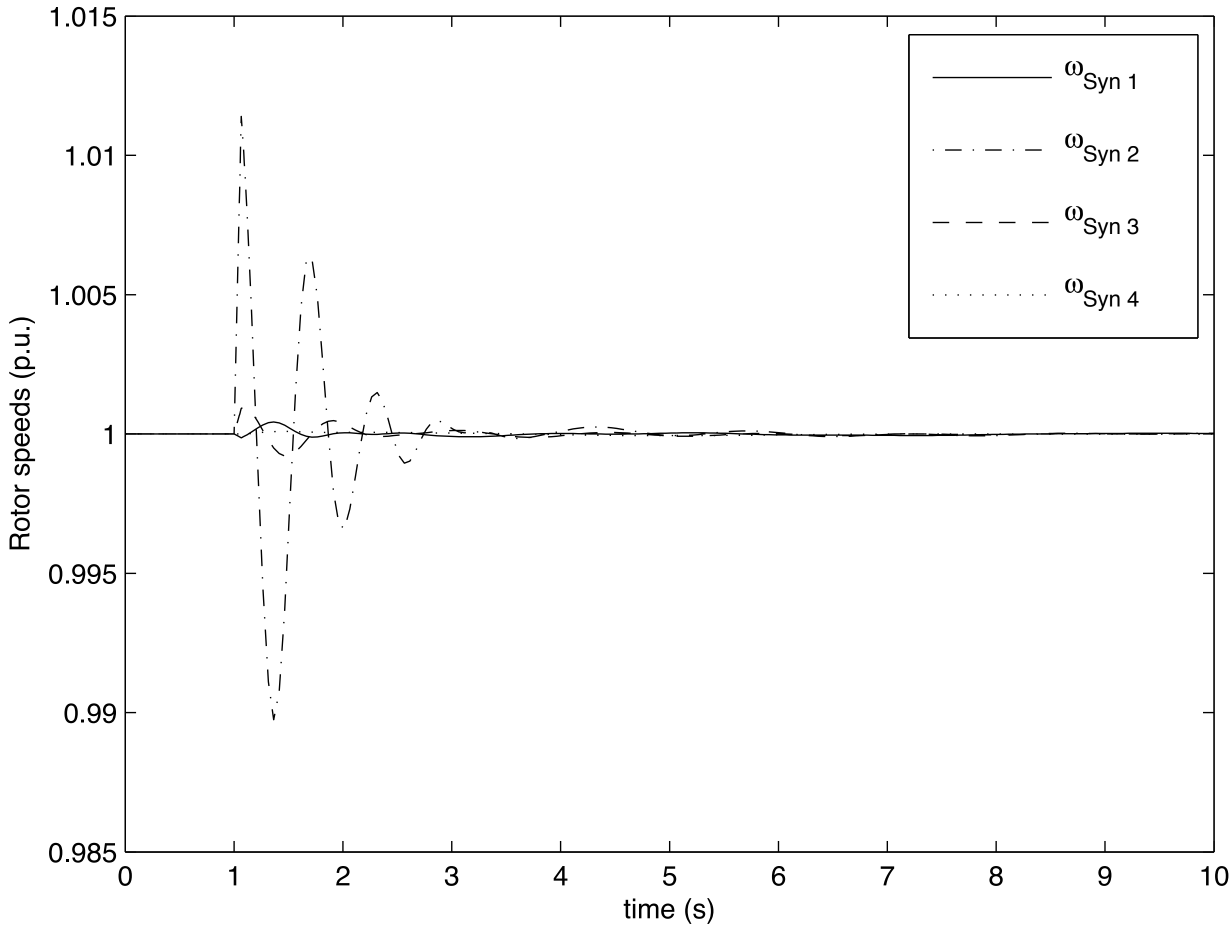

Fig. 6. Rotor speed plot for the 9-bus system.