

PHOTOVOLTAIC HYBRID SYSTEM SIZING AND SIMULATION TOOLS: STATUS AND NEEDS

Dave Turcotte^a, Michael Ross^b, and Farah Sheriff^a

^a CANMET-Energy Diversification Research Laboratory
1615, Lionel-Boulet Blvd., P.O. Box 4800, Varennes, QC, Canada
Tel.: (450) 652-5572—Fax: (450) 652-5177
dave.turcotte@nrcan.gc.ca

^b GPCo inc, Varennes, Québec, Canada

ABSTRACT: A wide variety of tools, ranging from simple rules of thumb to sophisticated software packages, exist for the analysis and dimensioning of stand-alone photovoltaic systems. System designers and installers use the simpler tools for sizing. Scientists and engineers typically use more involved simulation tools for optimisation.

Numerous software tools exist, but it is sometimes difficult to assess the adequacy of these tools for specific tasks. Accuracy requirements are different for prefeasibility analysis, system design, optimisation and R&D. In addition, input and output requirements are affected by the information known about the system configuration, which changes as the project advances.

This paper presents the current status of PV system software tools by surveying and categorising some of the most common programs available today. Following this, it assesses the needs for future development in simulation and sizing software.

Keywords: Software, status, simulation, sizing

1 INTRODUCTION

PV-only systems are relatively straightforward to design and simulate. Energy flows from one source to one set of loads with a delay function imposed by the battery; the energy source (i.e., the PV array), can not be dispatched, and the load can not generally be deferred. Hybrid systems, however, add a new dimension to design and simulation: the time-correlation of intermittent sources (e.g., PV and wind) must be evaluated and the dispatch strategy of sources providing power on demand (e.g., the genset) must be chosen. Consequently, pre-feasibility assessment, sizing and optimisation of these systems involve a more in-depth analysis.

This paper presents an overview of the software tools available on the market and categorises them based on their use and form. Due to the large number of tools, this list is not exhaustive. The tools are not rated or ranked here, but their distinguishing features and common traits are noted.

Finally, based on the survey of tools available, an assessment of the need for future software development is presented.

2 CATEGORIES OF SOFTWARE

No tool can perform every imaginable task: while a tool designed to fulfil a

certain need may work for other purposes, it may not be as easy to use or as accurate as one designed specifically for the task. Software tools related to photovoltaic hybrid systems can be classified into four categories: pre-feasibility, sizing, simulation and open architecture research tools. This classification is based on the form and purpose of the software.

2.1 Pre-feasibility tools

A pre-feasibility tool automates the calculations that an engineer would normally do by hand. It helps to determine whether a PV system makes sense for a specified application, both in terms of the energy provided and the life-cycle cost of the energy. These tools are usually geared toward a rough sizing but often have a comprehensive cost and financial analysis.

Pre-feasibility tools are often implemented as spreadsheets since they require only the automation of simple calculations, with little iterative work. More advanced pre-feasibility tools also include embedded macros or code to perform more detailed analyses.

These tools are typically used by vendors, system promoters, energy system consultants, community energy planners, renewable energy financiers, and other people who need to evaluate whether an opportunity exists for a specific PV system application.

2.2 Sizing tools

The sizing tool performs dimensioning of the system: given an energy requirement, it determines the optimal size of each of the different components of the system. Different tools may optimise for different objectives. Some will attempt to explicitly

minimise the life-cycle cost of the system, while others may size the system according to rules that, it is assumed, lead to a properly functioning system. Most sizing tools provide detailed information about energy flows among components and indications of the critical periods during the year.

Sizing tools are usually small, compiled software packages. They generally have a user interface designed to be quick and easy to use. Often supplied by PV or genset manufacturers to their dealers, they also exist as commercial software packages. Sizing tools are the type of software most often used by system installers.

2.3 Simulation tools

With simulation tools, as opposed to sizing tools, the user must specify the nature and size of each component. The tool then provides a detailed analysis of the behaviour of the system. The time resolution of the simulation (i.e., the length of the time step), varies among simulation packages and depends on the level of detail required and the availability of input data (e.g., weather data). Hourly simulations, which are common, can be used to verify system sizing, investigate the impact of future changes in the load, look at performance under atypical conditions (e.g., worst-case weather), investigate the sensitivity of the design to various parameters, or analyse the impact of the failure or deterioration of the components. Simulations can also provide information concerning the financial and environmental characteristics of the system, such as the life-cycle cost and CO₂ emissions.

Simulation tools can also be used for sizing. This requires that the user correctly identify the key variables and then repeatedly run the simulation, adjusting the variables manually to converge on an acceptable sizing. Some packages automate this process.

Simulation tools are usually compiled software sold on the market by universities and research centres. They are often the products of their in-house research tools, many of which fall into the category described in the next section.

2.4 Open architecture research tools

Performing R&D at component and systems level requires a high level of flexibility in the interaction of the components. While traditional simulation tools can perform extensive sensitivity analyses, they generally do not permit the user to modify the algorithms that determine the behaviour and interactions of the individual components. For this, an open architecture is required: the software consists of a selection of “routines”, describing the components, and platform for linking these routines together. The user is at liberty to modify the routines or add wholly new routines. Such research tools can be either implemented within a commercially available, general-purpose simulation environment, or programmed and compiled in a language such as Fortran, C or Pascal.

The flexibility and power of open architecture research tools make them the tools of choice of research organisations; their concomitant complexity limits their usefulness for commercial system analysis, sizing and design. A subset of the routines in the tool can usually be compiled and

distributed commercially, however. The result is typically a traditional sizing or simulation tool.

3 SOFTWARE TOOLS AVAILABLE

This section presents some of the most common tools found on the market in each category.

3.1 Pre-feasibility tools

3.1.1 FATE2-P

FATE2-P 3.1.1 [1] is a financial analysis tool developed by the United States National Renewable Energy Laboratory (NREL) and Princeton Economic Research, Inc. It calculates the cost of energy or the internal rate of return for alternative energy power plant projects, taking into account such financial considerations as taxation, debt, and production tax credits.

3.1.2 RETScreen

RETScreen [2] is a renewable energy awareness, decision-support and capacity building tool developed by the CANMET Energy Diversification Research Laboratory (CEDRL). The core of the tool consists of a standardised and integrated renewable energy project analysis software based on Microsoft Excel spreadsheets. It assists the user in determining the energy production, life-cycle costs and greenhouse gas emission reductions for various types of renewable energy technologies (RETs) including photovoltaic hybrid systems. Figure 1 shows an example of the cost analysis worksheet for RETScreen.

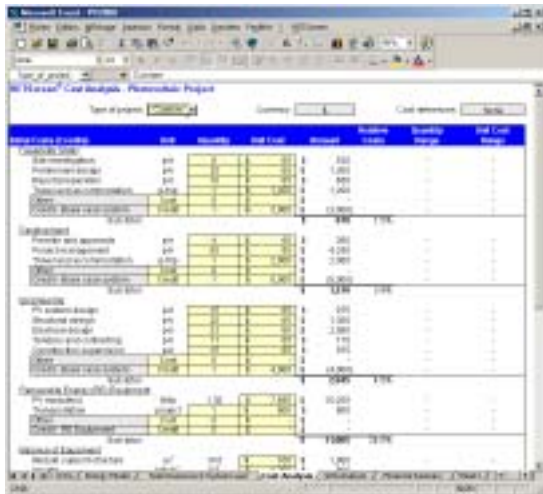


Figure 1: RETScreen PV Cost Analysis Sheet

3.2 Sizing tools

3.2.1 HOMER

The *Hybrid Optimization Model for Electric Renewables* (HOMER)[3] simulates PV/wind/genset hybrid systems. While an hourly simulation tool, HOMER's strength is sizing and optimisation. It does this by automatically running the simulation over and over, comparing different system configurations and component sizes. Developed by NREL, this tool offers a powerful user interface and accurate sizing with detailed analysis of the system. Figure 2 shows HOMER's comparison of various system configurations.



Figure 2: HOMER Screenshot

3.2.2 Hybrid Designer

Developed by the Energy & Development Research Center of Cape Town University, South Africa, Hybrid Designer [4][5] is a free sizing package for PV/wind/genset hybrid systems. Using a genetic algorithm, the tool evaluates different scenarios to determine the system configuration that will provide acceptable reliability at the least life-cycle cost.

3.2.3 PVSYST

PVSYST [6] integrates pre-feasibility, sizing and simulation support for PV and PV/Genset hybrid systems. After having defined the location and loads, the user selects the different components from a product database and the software automatically calculates the size of each component. Since the genset is only considered as a backup, the optimisation routine may miss the system configuration having the true lowest life-cycle cost, however. The user must consequently manually perform a sensitivity analysis, using PVSYST as the simulation engine, to improve the life-cycle cost of the system.

At the prefeasibility level, the "Preliminary Design" module of PVSYST performs a quick and simple financial analysis based on the location and loads, but this module does not support hybrid systems.

3.2.4 Proprietary Tools

Manufacturers of photovoltaic modules, inverters and gensets also develop sizing tools that they distribute to their vendors. For example, Trace Engineering, an inverter manufacturer, has developed "Quick System".

These tools are generally not publicly available. The vendor should also bear in mind that, unlike an independent research organisation, a manufacturer has an interest in selling one or more of the components being sized by the software. This may be reflected in the output of the software.

3.3 Simulation tools

Numerous tools are found in the simulation arena. The following non-exhaustive list references some of the most popular tools available on the market today.

- Ashling [7]
Developed by a consortium formed by NMRC-Ireland, ARMINES-France, ICI-Romania and IMIO-Poland.
- Hybrid2 [8][9]
Developed by NREL, USA.
- INSEL [10]
Developed by University of Oldenburg, Germany.
- PV-DesignPro-S [11]
- PVSYS [6]
Developed by Geneva University, Switzerland.
- RAPSIM [8]
Developed at Murdoch University, Australia.
- SAU/ARES
Developed by Cardiff University, United Kingdom.
- SOMES [12][13]
Developed by Utrecht University, the Netherlands.
- SOLSIM [4][14]
Developed by IAF / EWIS, Germany.
- WATSUN-PV [15]
Developed by University of Waterloo, Canada.

For all these tools, the user enters data describing system components, loads, location, etc. The program then simulates the system and outputs the energy production, consumption, and storage as a function of time. Some tools, such as PVSYS, Hybrid2 and PVDesign-Pro, also provide detailed financial analyses of the system life-cycle costs. Figure 3 shows the summary sheet of a simulation performed with PVSYS.

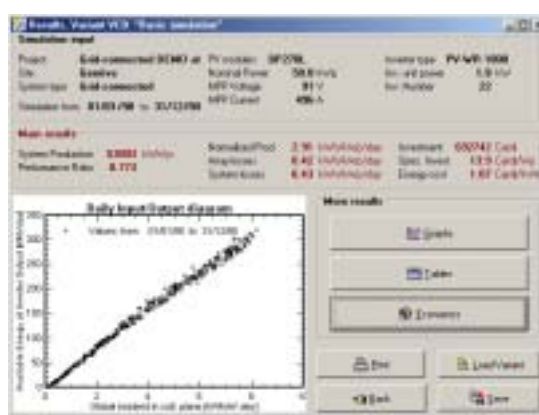


Figure 3: PVSYS Simulation Summary

3.4 Open architecture research tools

3.4.1 Matlab/Simulink

Matlab, developed by The Mathworks [16] in 1984 and subsequently upgraded several times, is a technical computing environment offering advanced mathematical manipulation tools with a powerful and intuitive scripting language. Coupled with Simulink, a graphical modular simulation environment, it provides an easy to use modelling and simulation tool.

The Mathworks provides multiple toolboxes for optimisation and systems analysis in addition to data acquisition hardware that can be linked to the simulation. While the routines are

powerful and varied, development of hybrid system simulations is not trivial. The Simulink interface is easy-to-use, but the platform assumes that the system is readily modelled as a system of differential equations. The solvers can be sensitive with closed-loop, non-linear systems, including hybrid power systems with battery storage. Experience and knowledge of the system behaviour is essential to ensure the modularity of the models.

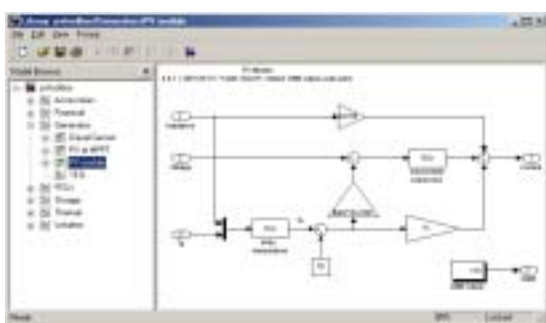


Figure 4: A Simple Model in Matlab/Simulink

3.4.2 PSpice

PSpice [17] is a simulation tool developed for computer-aided design of electronic circuits. By modelling PV system components by their equivalent electronic circuits [18], one can use PSpice to run simulations and verify the impact of different topologies and control techniques on the system.

3.4.3 TRNSYS

Available commercially since 1975, TRNSYS [19] (pronounced “tran-sis”) was initially developed for modelling of thermal energy flows in multiple zone systems. It is a transient system simulation program based on a modular architecture of Fortran code blocks. Hundreds of components are available, including PV arrays, charge controllers and weather generators. TRNSYS’s extensive use of

Fortran implies that operators are familiar with this programming language, at least at the development level.

3.4.4 General Purpose Programming Languages

Simulation environments offer the great advantage of ready-to-use modules and user interfaces that can be combined relatively easily. On the other hand, the environment, its associated architecture and its mathematical solvers impose a certain framework on the project. Total freedom can only be attained with the development, from scratch, of a piece of software using a general-purpose programming language such as Fortran, C, Pascal, etc. This implies a huge resource investment, however. Surprisingly, for a truly useful tool the user interface often requires as much effort as the development and implementation of the simulation algorithms. Some hybrid system component codes [20] are commercially available. This eases the task of those who chose this approach but raises the concern of licensing component codes; a restrictive license may impair the distribution of the final product.

Engineers and scientists may be strongly tempted to engage in the development of simulation software, but they should remember that after the thrilling part of the algorithm development and implementation will come the lengthy debugging phase and the typically boring user interface construction. Too many software projects never reach an acceptable conclusion due to insufficient consideration for these latter, less glamorous tasks. Consequently, when allocating human resources for such projects, a skilled programmer should be

included. Once the core of the tool is built, engineers and scientists may “tweak” it, while always ensuring that changes and improvements are properly documented.

4 NEEDS

4.1 Modifications to Software

The survey above shows that many tools already exist, but most of these are for simulation.

There are relatively few pre-feasibility tools. RETScreen’s ability to compare different renewable energy technologies applied to the same project is very useful, but, like PVSYST, it is presently incapable of dealing with PV/Genset/Wind systems.

While PV product suppliers have developed adequate tools for PV-only systems, their hybrid system tools are less advanced. Excellent sizing tools have been developed by independent research organisations, however. These tools, while providing lots of features, comparisons among different configurations, and real optimisation, can take considerable time to find a solution due to their computer-intensive sensitivity analysis.

Sizing tools generally lack flexibility in terms of the system control algorithm; ideally this could be adjusted to match that used by the designer. A sizing software with control algorithm plug-ins could be an interesting product that would allow designers to keep their control techniques proprietary while permitting a standard sizing tool.

As noted earlier, many simulation tools are available. Hybrid2, Simes, PVSYST and others have been available for a reasonable

period of time, offer a good user interface and utilise a relatively accurate and robust simulation algorithm.

As with sizing tools, not all programs are fully flexible in terms of the control system algorithms. Another highly useful feature that is not always included is command line, COM (Computer Object Model) or DDE (Direct Data Exchange) support to perform automated sensitivity analysis with an external script or software tool.

While existing environments for open architecture research tools are adequate, a library of good component models that can easily be connected together is still needed. Increased international collaboration to develop such a library would both avoid redundant efforts and facilitate comparison of simulation results.

Current models for the PV generator and wind turbine are probably sufficient for most hybrid system simulation purposes. The components that need to be investigated further are the battery and the genset. This is especially true of methods for predicting the lifetime of these components, such that the ageing effects of different operating strategies can be investigated.

Existing genset and battery models do not usually account accurately for changes in the operation and lifetime expectancy of these components at low temperatures. This is a key consideration, given that hybrid systems are presented as a solution to the problem of diminished photovoltaic output during winter. Also, existing packages lack support for waste-heat recovery from the genset. This heat can be a valuable resource in cold climate

conditions, but currently simulation packages can not optimise its use.

There is also a need for integrated tools, i.e., the approach of PVSYST. Instead of claiming a simulation tool to be good for design and vice-versa, PVSYST provides in the same tool preliminary design and system design tools, which is advantageous for system dealers. Some effort will be required to adapt this to hybrid systems, but the approach is promising.

4.2 Building Credibility

There can be no doubt that the number, range, and sophistication of software for hybrid systems has increased considerably over the last decade. What must now be considered is whether better hybrid systems are being built as a result of this better software. Two questions must be asked:

- 1) Do system designers and vendors trust their software to provide the best estimate of system design? Or do they put in a “safety factor”? If the latter is the case, then one of two situations exists—either the software is inaccurate or the software is right and the safety factor inflates system cost needlessly.
- 2) Can a researcher confidently evaluate the impact of a new concept, configuration, or component? Or will inaccuracies and limitations in the software mask the impact of the new component or cast doubt on the conclusions?

There is evidence that existing tools are lacking in both concerns. This suggests a need for better validation of software tools. That is, monitored output from real

systems should be compared with simulation and the methodology and results should be published in refereed journals for all to comment on. A good start would be a public pool of high quality data sets from monitored systems.

Serious validation would do two things. First, it would establish where improvements are needed and give an indication of the software accuracy. Second, if software is accurate, it would be a service to hybrid system buyers as well as honest vendors to know that they should trust their software and pare back their safety margins.

An allied issue is certainty. Existing tools are almost exclusively deterministic, i.e., they state their results as numbers with infinite precision. But there is great uncertainty associated with the inputs to these tools, such as weather data, and the models themselves introduce further uncertainty. It is naïve to accept the results of these tools without any indication of the certainty of the results.

For example, consider a software package that ranks different power supply options according to the cost per kWh of electricity provided (see Figure 5). The top four options vary from, say, \$0.435 to \$0.471/kWh, and the capital costs for these options vary from \$11,000 to \$31,000. One can be sure that the differences in the capital costs are real, but how real are the costs of energy? If the combined precision of the tool and the input data is only to within 10%, or about \$0.045/kWh, there may be no real difference in the costs of energy between these four options.

Categorized Rankings					Overall Rankings					Graphic Display				
← Double click on a solution for details.														
					PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Total Capital	Total NPC	COE (\$/kWh)	Ren. Frac.
					0	0	1	8	25	4.0	\$ 23,717	\$ 79,277	0.435	0.26
					1	0	1	8	25	4.0	\$ 30,717	\$ 80,535	0.442	0.34
					0	0	0	8	25	1.5	\$ 10,594	\$ 82,830	0.455	0.00
					1	0	0	8	25	4.0	\$ 19,417	\$ 85,792	0.471	0.07
					0	0	0	8	0	0.0	\$ 7,000	\$ 100,332	0.551	0.00
					0	0	2	8	0	4.0	\$ 32,517	\$ 105,214	0.577	0.42
					1	0	0	8	0	1.5	\$ 15,094	\$ 109,222	0.599	0.07
					1	0	2	8	0	4.0	\$ 39,517	\$ 109,517	0.601	0.46
					16	0	1	0	200	8.0	\$ 149,133	\$ 181,048	0.994	1.00

Figure 5 Sizing Tool Output

Although it will be very difficult, tools should attempt to supply a measure of the certainty of their results. Furthermore, optimisation packages should give indications of whether an optimal design is found on a “broad plateau” or a “sharp peak”. In the former case, results will be insensitive to changes in design and inputs, whereas in the latter any difference between the system as simulated and the system as built and operated will cause significant deviation from optimality.

5 CONCLUSION

There are many software tools on the market but it appears that none perform all the tasks needed by photovoltaic hybrid

system designers. In summary, there are a number of important considerations in the selection and design of software tools:

- The use to which the software will be put—i.e., the category;
- Potential integration of the tasks (pre-feasibility, sizing, simulation) into the same tool;
- Ease of use;
- Portability;
- Modularity of components;
- Validation of the tool and levels of accuracy and precision;
- Support for low temperature operation and waste-heat recovery; and,
- Flexibility in the choice of control algorithm.

The need to research and develop new hybrid system components, configurations, and control algorithms will continue to require the use of open architecture research tools such as Matlab and TRNSYS. This will facilitate the development of in-house tools; eventually the fruits of their research may be reflected in off-the-shelf packages. International collaboration on these in-house tools would be highly beneficial to the progress of the industry.

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