World-wide overview about design and simulation tools for hybrid PV systems

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Background:

The International Energy Agency Photovoltaic Power System Executive Committee has launched a new Task 11: "PV Hybrid Systems within Mini-grids" for the period 2006-2011. This Task builds on the work on PV hybrid systems undertaken in PVPS Task 3 and currently includes participants from 11 IEA countries. The subtask 11 inside the IEA Task 11 deals with the Evaluation and comparison of system design methodologies and tools and development of guidelines for design tools

Purpose:

Off -grid systems, and in particular hybrid systems, are characterised by a high degree of complexity at the dimensioning stage. For this reason, as similarly in many other fields, software simulation is an important aid. There is already a broad diversity of such programmes on the market. Some are very comprehensive and perform their calculations down to a very detailed level, where as others are rather more suited for fast »coarse dimensioning«. The different programmes integrate different sets of technologies (PV, wind, additional generators, …), and some include also economic calculations. The costs of the software vary no less significantly, which often makes it difficult to find the best package for the task in hand.

Approach:

To get a world-wide overview of the existing and used software and their features a survey was initiated. The survey questionnaire and subsequent analysis dealt with

- Tool availability (generally available or proprietary) and cost,
- Tool features and application area (e.g. used models and software code, feasibility analysis, system sizing and design, simulation)
- Characteristics and quality of user interface and documentation

Results:

Results were obtained for over 20 software tools, see table 1. In addition to tools focused on PV hybrid systems, the survey also gathered information on tools for the design of distribution networks for mini-grids.

Supplemental to this survey the German Conergy subsidiary SunTechnics in Hamburg decided it was time to address the question which is the best suitable software and proposed this as a diploma thesis /1/ to the FHTW Berlin (University of Applied Sciences) with support from Fraunhofer ISE in the summer of 2006. The task was to analyse those programmes on the market which are specifically able to model hybrid systems (PV-diesel batteries) and which appear to promise a short familiarisation period. The result are seven selected simulation

programmes, see table 2, which are relative well known and the familiarisation process is relative easy /2/.

free tools

Retscreen	Dim
HOMER	Dim/Sim
Hybrid2	Sim
Vipor *	Dim/Sim
Jpélec *	Dim/Sim

* design of distribution netwok

commercial tools

Off Grid Pro	Des
PVSYST	Dim/Sim
PVSOL	Dim/Sim
Solar Pro	Sim

standard commercial system simulators

Simplorer (APL)	Dim/Sim
PowerSim	Sim
Matlab Simulink	Sim
Dymola	Sim
PowerFactory	Sim

internal tools

Off Grid Sizer	Des	Conergy
sunny island design	Des	SMA
PVS	Dim/Sim	ISE
TALCO	Dim/Sim	ISE
Matlab Simulink PVToolbox	Sim	Canmet
Matlab Simulink Hysis	Sim	CIEMAT
Matlab Simulink N.N.	Sim	ISET
PowerFactory Tool box	Sim	ISET

Table 1: Overview of used simulation tools as results from questionnaire

The table 2 assessed the 7 programmes according to a catalogue of different criteria as follows:

- The assessment of the instruction manual quality considered the scope of information given, the clarity of presentation and the ease of understanding for the user.
- Factors contributing to user-friendliness were the structure and intuitive nature of the user interface, and the number of inputs necessary to reach a chosen programme function.
- Under component dimensioning, it was determined whether and for which components this function is available, as similarly for the simulation option.
- The feature plausibility check refers to checking of the technical feasibility of specified configurations and the issuing of warnings in case of discrepancies.
- Under irradiation database, it is indicated whether such a database exists, and whether it is possible to perform shadowing analyses.
- Where the emission balance feature is present, the emissions of various gases with negative climate effects are calculated, alongside the pollutant savings achieved by renewable energy generation. Economic analyses comprise investment and cost calculations over a given period.
- The criterion clearness of data input is considered separately for users and the system components. The assessment of the two input procedures considers the clarity of the input form layout and the effort required to enter a particular item of data. In the case of the system components, important factors were the integration of databases and the possibilities to expand these databases.
- The assessment of the result output clarity considers the layout and variants for result presentation (e.g. graph, table, scatter plot). The time resolution of the results is given and the scope and presentation of the project reports and print-outs is evaluated.

Software	Dimensioning (Dim)		Dim. + Sim.		Simulation(Sim)		
Programm	**PV-SPS**	**RETScreen**	**PV-SOL**	**PVSYST**	**Hybrid2**	**PV-DesignPro**	**HOMER**
Version	2.0	Version 3.2	2.6 R5	v3.41	1,3c R3	v6,0	2.2 beta
Date of 1.version	2001	2005	2006	2006	2004	2004	2005
Date of recent version	2001	1997	1998	1994	1998	1998	1993
Costs (single license)	99 (A $) = 58 Euro	free	498 Euro	700 (CHF) = 465 Euro	free	259 US $	free
Language versions	Engl.	Engl., French	Ger., French, Engl., Spain, Ital.	French, Engl.	Engl.	Engl.	Engl.
Instruction manual quality	(1)	+	+	detailled F1 man.	-	o	+
User background knowledge	Normal	normal	normal	normal	high skilled	normal	skilled
User friendless	O	+	o	o	-	o	+
Component dimensioning(2)	PV-D-B	PV-D-B	PV-B	PV-B	no Dim.	no Dim.	(3)
Simulation (2)	no Sim.	no Sim.	PV-D-B	PV-D-B	PV-D-B-W	PV-D-B-W	PV-D-B-W-(+)
Plausibility check	Yes	no	yes	yes	no	no	yes
Irradiation data base	4 locations	yes + NASA link + S	yes + S	yes + S	yes	yes + S	yes + NASA link
Wind data base	No	yes	no	no	no	no	no
Emission balance	No	yes	yes	no	yes	no	yes
Economic analysis	No	yes	yes	yes	yes	yes	yes
Clearness of data input for users	O	+	-	o	-	-	+
Clearness of data input for system components	+ (4)	+ (5)	+	o	-	+	+
Result output clarity	+	+	o	o	-	o	+
Time resolution of the output	month, year	month, year	hour, day, week, month, year	hour, day, month, year	User-defined	hour, day, week, month, year	hour, day, week, month, year
Project report/ printout	O	+	+	+	-	o	+

Table 2: Overview of dimensioning and simulation programmes for hybrid PV systems (+ good/easy, 0 satisfactory, - sufficent/laborious, S shadowing analysis

1) No separate manual, the tool should only be used in conjunction with the relevant Australian standards for off-grid-systems (AS 4509 Parts1, 2 & 3 and AS 4086 Part 2)

2) PV = PV-generator; D = diesel-generator; B = batterie; W = wind generator; (+) =further energy sources, e- g. biogas, fuel cell

3) If several components of different sizes are entered, all the possible combinations are simulated and combination proposals are listed on the basis of their economic viability.

4) No component database available

5) PV module database is not extendable by the user

The seven programmes can be divided into three groups: dimensioning programmes, which calculate the system dimensions on the basis of input data (load and climate data and system components), and simulation programmes, which use the input data (load and climate data, system components and configuration) to simulate the behaviour of the system over a given period. The third group comprises programmes which offer both options.
The individual programmes are to be presented here in more detail.

PV-SPS (Version 2.0)
PV-SPS (PV Stand-alone Power Systems) is a dimensioning programme for PV-diesel off - grid systems based on Excel spreadsheets. It performs its calculations to the Australian industry standards and was developed by the Australian Business Council for Sustainable Energy (BCSE). It demands a certain level of prior knowledge for the specification of the consumers and system components and is thus aimed above all at experienced users in the off - grid field. Furthermore, it should only be used in conjunction with the relevant Australian standards for off - grid systems (AS 4509 Parts 1, 2 & 3 and AS 4086 Part 2)! One special feature of PV-SPS is the distinction between summer and winter, for which two groups of consumers (one for each season) need to be entered. In addition, regional factors are specified for each month for seasonal consumers, alongside irradiation and temperature data for four different locations in Australia. The programme outputs on the one hand three different PV generator sizes, based on the mean irradiation values of the best and poorest months, as well as the annual mean value, and on the other hand the size of a diesel generator corresponding to the selected system operating mode. Even though the layout of the individual input forms is not always optimal in terms of clarity, the two graphs presenting the monthly energy consumption and power generation give a good general impression of the system performance over the course of the year.

RETScreen (Version 3.2)
This programme, which is based on Excel spreadsheets, was developed by the Canadian government (Ministry of Natural Resources) and includes not only the actual dimensioning calculations for PV-diesel off - grid systems, but also options for cost and emission gas analyses. RETScreen stands out by way of its fast and simple input, as databases are provided for PV modules and climate data (month-by-month solar irradiation and temperature data for the year). Via a link to the NASA Internet site, climate data can also be retrieved for any chosen point on earth. Further components can only be defined with a limited scope of technical specifications, which means that the output configurations should best be treated as dimensioning guidelines. Economic viability and emissions calculations can be performed for the dimensioned system. The programme is offered in English and French language versions, (new version RETScreen 4 is available in more than 20 languages and includes a wide variety of additional tools covering i.e. Biogas, Wind, Water, Heating) together with a comprehensive manual and a collection of case studies. It can be downloaded free of charge at the following Internet address: www.retscreen.net/ang/t.php.

PV-SOL Professional (Version 2.6 R5)
PV-SOL, which was developed by Dr. Valentin Energiesoftware GmbH in Berlin, Germany, is a time-step simulation programme for off -grid and grid-coupled solar generation systems and is able to perform energy yield calculations, analyses of economic efficiency and the influences of shadowing. Besides the full simulation over time, there is also a »quick design« function for off -grid systems, though this is limited to dimensioning of the PV generator and accumulator (no additional generator). The consumers can be entered either in very fine detail (individual consumers and their operating times) or by way of a general specification of

annual energy consumption and selection of a load curve. The »quick design« can be taken over into the simulation and supplemented accordingly (e.g. with an additional generator). Before the actual simulation is started, a plausibility check is performed and any inconsistencies are pointed out to the user. The simulation results are output in graph form (characteristic curves for specific parameters) or tables, with the possibility to output up to eight different variables at once. The system report (as a print-out or export file for further processing) comprises a system diagram, the most important technical data of the system and energy balances. In the actual situation it is also possible to buy only the on-grid (PV*SOL gridcon 3.0) or the off-grid (PV*SOL standalone 3.0) sections of the programm as separate products.

PVSYST (Version 3.41)
This time-step simulation programme, developed at the University of Geneva, Switzerland, is able to simulate both grid-coupled and off -grid systems (energy flow, shadowing and economic viability). It provides dimensioning proposals for stand-alone installations (PV generator and battery size), and warns the user if the chosen component combinations are not technically feasible. The dimensioning proposals are calculated on the basis of load inputs, specification of the number of days for autonomous operation and an estimation of the so-called »loss-of-load probability«, i.e. the duration for which the load cannot be served by the PV and battery energy. As there are no inverters, it is only possible to model DC systems. The additional generator serves only to charge the batteries. The consumers can be specified in various ways: individual inputs, load profile creation, probabilities of particular power values, data import and differentiation of individual periods. Comprehensive component databases are provided, permitting new components to be entered by way of typical technical data. The output options for the calculation results are similarly extensive and offer a wide range of presentation forms (e.g. characteristic curves of specific parameters, scatter plots, histograms, printed reports).

Hybrid2 (Version 1.3c R3)
The pure simulation programme developed by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy in cooperation with the University of Massachusetts is one of the pioneer programmes in the field. It was conceived for analyses of hybrid systems with several energy generators (PV, wind and diesel generators) and consumers (AC, DC and thermal loads) and offers not only a broad spectrum of energy management strategy options, but also an economic analysis function. While the input forms are well structured, the output options fall back somewhat in terms of user-friendliness and clarity. Hybrid2 is used especially in universities and colleges, not least because it requires a certain time for familiarisation, but it does then permit very comprehensive system analyses. Hybrid2 is available only in English and can be downloaded free of charge at the following Internet address: www.ceere.org/rerl/projects/software/ hybrid2

PV DesignPro (Version 6.0)
Developed by Michael Pelosi from Hawaii, this time-step simulation programme is designed to simulate both grid-coupled and off - grid systems with PV and wind generators. The output of an additional generator only represents the shortfalls in renewable energy, meaning that a real additional generator cannot be modelled. In addition to the energy balance calculations, the programme incorporates also economic analysis, an optimisation tool, and a set of »sub-programmes« which can be used to create load curves and to convert Meteonorm data (a special climate database that includes data from all over the world, the distributor comes

from Switzer land) into the PV DesignPro data format. Alongside a quite comprehensive internal climate database with temperature, irradiation and wind data, component databases are also provided. Further PV modules, how ever, can only be entered by specifying technical data based on a special test procedure. Although the programme PV DesignPro is only available in English, an additional Spanish-language manual is included and supplied with the package.

HOMER (Version 2.2 beta)
HOMER (Hybrid Optimisation Model for Electric Renewables) – another time-step simulation programme developed by NREL – simulates the annual performance of each of the system combination possibilities for a specified set of energy sources and calculates also the system and operating costs over the given period. It is also possible for the user to define sensitivities (e.g. different mean values for solar irradiation, wind or power consumption) to close down the range of results. The outcome of the simulation is a list of the possible systems in order of the arising costs. A graph depicts the various ranges of the most profitable systems over the given operating period, based on the selected criteria. Detailed results can be output for each of the individual simulated systems (graphs, tables, scatter plot, print-out). The programme design is very user-friendly and incorporates not only PV, wind and small-scale hydro-generators, but also further addition al generators driven by a variety of fuels (e.g. diesel, bio mass, ethanol, hydrogen). To get plausible values for the battery lifetime costs a good understanding of battery lifetime behaviour and of the used battery lifetime model inside HOMER is necessary. No check is made, however, to determine whether the entered component combinations are also technically compatible, for example because the PV generator is modelled merely by way of its peak output and not, as in other programmes, by way of the individual PV modules. Even so, HOMER is a very convenient tool, especially where the economic aspects of a system are to be considered.
The tool is continually worked on to incorporate more and more boundary conditions.
Latest Version 2.63

Summary
The programme descriptions and overview table show that each of the programmes has its pros and cons. The user must therefore be aware of the features which are most important for his particular case, and should then test the programmes which meet these criteria. Most of the commercial programmes are also available in time limited demo versions. One of the key decisions to be made by the user concerns the desired focus of the calculations: economic considerations (HOMER), general dimensioning (RETScreen), a detailed technical configuration (PV-SPS, PV-Sol, PVSYST) or system analysis (Hybrid2, PV-DesignPro). In conclusion, it must be pointed out that the results of the system design and system simulation are dependent not only on the calculation algorithms of the programme concerned, but also to a high extent on the quality of the input data, i.e. the technical knowledge and experience of the programme user. The software will prove a very useful aid during the process of system identification. The output results, however, should always be appraised with the due critical objectivity!

Literature
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