REVIEW OF DIFFERENT SOFTWARE SOLUTIONS FOR THE HOLISTIC SIMULATION OF DISTRIBUTED HYBRID ENERGY SYSTEMS FOR THE COMMERCIAL ENERGY SUPPLY

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ABSTRACT: Innovative commercial energy supply solutions combine CHP plants with renewable energy sources like PV, solar thermal or heat pumps, which results, under careful planning, in a profitable, yet sustainable hybrid distributed energy supply scheme. To get to this optimal, ecologically beneficial as well as economically advantageous system design and operation strategy a holistic modelling and simulation of the energy supply scheme is inevitable. This paper designs and tests an objective method to help users in finding a suitable simulation tool for a specific distributed generation project. This is done by firstly defining requirements and ranking them based on their importance for the project, followed by a detailed software finding phase, and finally the evaluation of the identified software solutions based on the requirement catalogue. The method is exemplarily applied and a limited overview over existing software solutions is presented. All of this helps any kind of interested user to find the optimal simulation software for a specific hybrid distributed energy generation project.
Keywords: Hybrid Distributed Generation, Commercial Energy Supply, Simulation Software

1 INTRODUCTION

Today companies are offered a wide variety of different energy supply schemes to choose from based on their specific requirements. Especially innovative distributed energy supply schemes have become popular, as they are an efficient and reliable source of all kinds of energies [1, 2]. A special benefit of those systems is the interconnection of different energy forms, e.g. electricity and heat or heat and cold. This leads to an efficient usage of available energy which is not always possible in current, centralised supply schemes [1]. The holistic view on energy flows in companies is vital to come to an optimal energy supply concept. Especially combining electricity and heat/cold energy supply in some form might influence the overall efficiency and thus economic aspect of energy supply [3-9]. Today mostly combined heat and power (CHP) plants are used to achieve this target. By combining a CHP with a renewable energy form like PV or solar thermal a flexible and reliable yet cheap energy supply system is formed [3, 5-7, 10-12] which is called hybrid distributed supply scheme [13]. The exact decision on which kind of system a company should invest in, looking for the maximum profit and therefore minimal cost of energy supply, is therefore as difficult as never before.

Hybrid energy supply feature complex interconnection of different technologies, country-specific funding and legislation and are highly dependent on outer influences. This leads to a high number of different options on how to provide energy in an optimal matter, making it difficult for current simulation software to model such systems. Therefore specialised software has to be used in order to get reliable results. There exist a large number of different software solutions to help certain users in their distributed generation project [14, 15]. Choosing the right software for the right project is vital to achieve a correct and relevant result. In this paper a methodology is introduced to structure the decision process and an exemplary case study is presented showing a short overview over available software solutions.

2 CLASSICAL, DISTRIBUTED AND HYBRID ENERGY SUPPLY

A **classical energy supply scheme** as used in many industries today is based on a complete separation of heat and electricity supply. Electricity is purchased from the grid; heat is produced in some sort of fossil fuel fired boiler.

In contrast, **distributed energy supply** describes mainly electricity generation either as part of the distribution network or even in the customer site of the meter [1]. Common approaches are combined heat and power (CHP) plants, photovoltaic (PV) or wind turbines (WTG) [2].

By using more than one distributed energy generation technology, the setup formed can be classified as being a **hybrid distributed energy system** [13]. Those kinds of systems feature different kind of generation concepts to supply the same kind of energy. This gives the operator the opportunity to decide at every point in time, based on the current load, forecasts and market prices, which kind of energy generation or combination of those might be the optimal one to use. To get even more freedom and possibilities some sort of storage might be added. This could be every sort of battery storage but thermal storage might be especially helpful [16, 17]. The interconnection and especially the operating and control strategy of those hybrid systems is critical to get to a profitable design [5, 9, 18] . A careful planning of which equipment to invest in and how to operate it is crucial before erecting equipment at site. This does not only include technical aspects but as well the skilful utilization of market opportunities and governmental subsidies [19].

3 SIMULATION OF DISTRIBUTED HYBRID ENERGY SYSTEMS

Specialised simulation software is used in the planning process of distributed hybrid generation to ensure a reliable result and therefore an economically beneficial energy supply scheme.

3.1 Simulation of complex systems

In general simulation of any kind of system is necessary, when its behaviour cannot be analysed and explained by simple theoretical and analytic methods. To do so, a model of the real-life system is constructed. The development of this model over time is then called a simulation [20]. With this procedure the time-dependent evolution of a complex system can be predicted without the need of working on the real-life system and therefore having to invest a lot of money and risking to destroy it.

A system is called complex when it consists of a large number of components which interact in a way that is non-linear and difficult to predict [20]. It can be positioned somewhere between an ordered and a chaotic system. This characteristics lead to a number of properties and features like emergence, resilience, and controllability which need careful consideration [20].

3.2 Simulation of complex energy systems

It should become clear from the basics of complex system simulation that energy systems, and especially electricity and heat supply, are a paragon for the application of simulation tools. These systems consist of a vast number of different technologies and components that are interconnected and therefore, in one or the other way, influence each other in a non-linear way. This is not only on a technical level but information like weather data, economic market behaviour and social factors play a vital role in the exact behaviour of energy systems. For that reason energy system analysis in form of modelling and simulation is a key part in today's energy research [20] and many ready-made simulation software tools are available on the market with rather different approaches. Each of these has its own right to exist and covers a certain fraction of the modern energy supply.

4 HOW TO FIND SUITABLE SOFTWARE?

In order to find appropriate software for a specific project a general comparison scheme of available software is developed. The process is structured in four subsequent steps:

1. Formulate Requirement Catalogue
2. Ranking of Requirements
3. Search For Existing Software Solutions
4. Evaluate Requirement Catalogue

In a first step, **formulate requirement catalogue**, the project specific hybrid distributed generation scheme is analysed from a technical, ecologic and economic, but pure theoretical point of view based on relevant literature, customer requirement and expert opinion. The mentioned requirements are then formulated and grouped for the later evaluation. Useful main categories are:

1. Basics
2. Technical
3. Economic and Legal
4. Ecological
5. Output

These main categories are divided in several sub-categories containing the identified requirements and thereby forming a comprehensive requirement catalogue. During the later on software tests the catalogue is constantly extended based on useful features found in the tested software.

Not every identified requirement is equally important to come to a reliable result, making a **ranking of requirements** advisable. Specialised post-processing tools are added manually without great effort and are therefore not as important as for example the correct simulation of certain kind of generation technologies, which, in most cases, cannot be added or manipulated by the user. Requirements are therefore ranked in three different categories: critical, relevant and optional.

The next step is to **search for existing software solutions.** This is done by different methods. There exist some scientific publications dealing with a general overview [14, 15, 21], but due to constant development of software a specific internet research is advisable to get up-to-date data. Another possibility is to contact different people working in this field and asking for their experience. The more software can be found the better the following decision for a software is.

The last step, **evaluation of the requirement catalogue**, brings together the identified and ranked requirements and found software solutions. Optimally, the software is installed (most software developers offer free trial versions) and tested following the requirement catalogue. For upcoming questions it is helpful to read the software manual or to contact the developers. The single requirements are then ranked from requirement fulfilled, partially fulfilled and missed. Counting the different missed requirements based on their relevance leads to a detailed overview over each and every software. The decision on which software to use can then be based in this objective evaluation of the requirement catalogue giving an objective view on the decision process.

5 CASE STUDY

To show the work flow of choosing suitable simulation software and to present a first overview over available software solutions an exemplary project is analysed. The project under investigation is defined as follows: The software is dedicated for an engineering office trying to sell hybrid distributed energy supply solutions to small- to mid-scale industrial customers in Germany. The main focus is on the early planning phase of such systems where the general outline of newly developed, innovative schemes should be tested.

In a first step the requirement catalogue is developed. Therefore a detailed literature research of technical, economic, legal and ecologic basics is followed by an intense discussion with the future users and decision makers. The final requirement catalogue can be seen in Table I. In the same step the users are asked for their priorities of the requirements which are depicted in Table I as well by the colour code defined beforehand.

Afterwards, several online forums, search engines, scientific publications, and experts were considered in naming suitable software. The software tools identified and analysed were:

- ***RETScreen Expert***: The software describes itself as a “Clean Energy Management Software” and is designed to enable professionals and decision-makers to estimate the technical and economic potential of a wide variety of different supply schemes.

- ***energyPLAN***: With this software energy flows on a regional or national level are monitored and forecasted to help taking long-term investment decisions and testing different legal support policies to come to a stable and reliable future energy supply system.
- ***HOMER Pro***: When planning micro-grid structures, especially off-grid, *HOMER* helps the user to optimize the system design and to get a good estimation about the system behaviour over its lifetime.
- ***energyPRO***: By combining a simple technical approach with a deep economic optimization *energyPRO* helps the user to not only plan the design of the energy supply scheme but as well help optimize its operation and interaction in every detail.
- ***Polysun***: When focusing on the final design of solar-based heat and electricity setups *Polysun* empowers the user to make a detailed analysis on how to interconnect the system on an electric and hydraulic level and on how to program the control units.
- ***TRNSYS***: *TRNSYS* is widely used in academia to investigate the technical aspect of energy supply. No other software offers such a detailed technical analysis. Unfortunately, economic aspects are only considered as a side-line.
- ***EINSTEIN***: Developed by an EU funded research project (EISAV/EIE/07/210/2007) *EINSTEIN* aims at monitoring the thermal energy flows in a technical production and trying to meet this demand in an optimal manner. Electricity is only simulated in really basic terms.
- ***COMPOSE****:* Based on a big community fed component database *COMPOSE* is a flexible simulation tool which adds features like risk analysis and innovative components to the field of energy system simulation.
- ***INSEL****: INSEL* is primarily aimed at the simulation of PV setups and treats other distribution generation plants only as a side-line. It is perfect to test different operating strategies of different components.

Every software found was tested in great detail and exemplary simulations were conducted. The scenarios tested consisted of CHP, PV, solar thermal as well as heat and battery storage supplying a standardized industrial electricity and heat demand. Special attention was given to the legal and funding requirements, which could apply to distributed generation, by placing the consumer under current German legislation und funding. This gives a good impression on how usable the software tools are for real life planning tasks as demanded by the company.

The findings were collected and evaluated by filling out the requirement catalogue as seen in Table I showing the great diversity of all approaches. The spectrum ranged from research aimed software like *TRNSYS* and *INSEL*, via decision-making, more political approaches found in *energyPLAN* and *RETScreen*, to a wide variety of tools with a high orientation to practical applications like *energyPRO* or *HOMER*. The resulting evaluation of the requirement catalogue can be seen in Table I as well and is summarized and evaluated in Table II by counting all missed requirements based on their importance.

Table II: Summary of the evaluated requirement catalogue based on the number of missed requirements per category.

	Missed requirements		
	critical (✓)	relevant (O)	optional (✗)
RETScreen	5	3	1
energyPLAN	3	7	1
HOMER	3	4	2
energyPRO	0	3	2
Polysun	1	2	1
TRNSYS	9	8	2
EINSTEIN	9	7	2
COMPOSE	9	8	1
INSEL	5	7	2

For the depicted use case the evaluation would result in the following Top 3 software:

1. *energyPRO*
2. *Polysun*
3. *HOMER*

Based on this evaluation the decision makers should be in the position to make an objective decision on which software is best suitable and are able to justify this decision to others.

Nevertheless, this process should not completely rely on objective measures, but as well take personal preferences, usability and other points into consideration which are difficult to measure. This is especially advisable when the result of the evaluation is not distinct and certain compromises are necessary. This procedure shall never replace the personal contact and discussion with everyone involved but helps in objectifying and structuring a subjective decision problem.

6 CONCLUSION AND OUTLOOK

This paper highlights the difficulties in modelling and simulation hybrid distributed energy supply schemes and gives a broad overview on how to find appropriate software, how to compare them and which ready-made software solutions are currently found in the market. This helps researchers and planning offices searching for an appropriate simulation tool to get a founded decision on which software to choose and what points to consider during this process. In general, the decision on which software to use for which project is mostly down to finding the best compromise between technical and economic focus and between detailed and rather broad analysis.

In the end this helps to get a detailed understanding how future energy supply might look like to come to a more intelligent and sustainable energy supply in the commercial sector.

Table I: Exemplary requirement catalogue of the case study (Sec. 5) where the project specific requirements are ranked from critical (✓) over relevant (O) to optional (✗) and the requirement fulfilment of every software is marked as being fulfilled (✓), partially fulfilled (O) or missed (✗).

		RETScreen Version 6.0.7	*energyPLAN* Version 12	*HOMER* Version 3.7.6	*energyPRO* Version 4.4	*Polysun* Version 10.0	*TRNSYS* Version 17.02	*EINSTEIN* Version 2.2	*COMPOSE* Version 3.14.11	*INSEL* Version 8.2.1
1	Basics									
1.1	Development State (✓)	✓	✓	✓	✓	✓	✓	✗	O	✓
1.2	Cost Price (O)	O (869$/yr)	✓ (Freeware)	O (500-1500$/yr)	O (3600-9000€)	O (1999-7300€)	O (5060-7830$)	✓ (Freeware)	✓ (Freeware)	O (1700€)
1.3	Service and Support (✓)	✗	O	O	✓	✓	O	✗	O	O
1.4	Programming Interface (O)	✗	✓	O	O	O	✓	✗	✓	✓
2.	Technical									
2.1	Generation									
2.1.1	Boiler (✓)	✓	✓	✓	✓	✓	✓	✓	✓	✗
2.1.2	CHP (✓)	✓	✓	✓	✓	✓	✓	✓	✓	O (Only electric)
2.1.3	Solar Thermal (O)	✓	✓	✗	✓	✓	✓	✓	O	✓
2.1.4	PV (✓)	✓	✓	✓	✓	✓	✓	✗	O	✓
2.2	Storage									
2.2.1	Thermal (✓)	✓	✓	✗	✓	✓	✓	✗	✓	✓
2.2.2	Electric (O)	✗	✓	✓	✓	✓	✓	✗	✓	✓
2.3	Consumption									
2.3.1	Electricity (✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓
2.3.2	Heat (✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓
2.3.3	Process Heat (O)	✓	✓	✗	✓	✓	✓	✓	✓	✓
2.3.4	Cooling (✗)	✓	✓	✗	✓	✓	✓	✓	✓	✓
2.4	Load profile generator (O)	✓	✗	✗	✗	O (Households)	O (Buildings)	✓	✗	✗
2.5	Manufacturing database (O)	O (US market)	✗	✓	✗	✓	✗	✓	O (Community based)	✓
2.6	Export of Electricity (✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓
2.7	Export of Heat (O)	✗	✗	✗	✓	✓	✓	✗	✓	✓
2.8	Stepsize =15min (✓)	✗	O (1h)	✓	✓	✓	✓	O (1h)	O (1h)	✓
2.9	Weather database (O)	✓	✗	✓	✓	✓	✗	✗	✗	✓
3.	Technical and Legal									
3.1	Costs									
3.1.1	Capital Related Costs (✓)	✓	✓	✓	✓	✓	✗	✓	✗	✓
3.1.2	Demand Related Costs (✓)	✓	✓	✓	✓	✓	✗	✓	✗	✓
3.1.3	Operation Related Costs (✓)	✓	✓	✓	✓	✓	✗	✓	✗	✓
3.1.4	Other Costs (✓)	✓	✓	✓	✓	✓	✗	✓	✗	✓
3.2	Proceeds									
3.2.1	Selling of electricity (✓)	✓	✓	✓	✓	✓	✗	✓	✗	✓
3.2.2	German Funding System (✓)	✗	✗	✗	✓	✓	✗	✗	✗	✗
3.3	German Legislation (✓)	✗	✗	✗	✓	✓	✗	✗	✗	✗
3.4	Sensitivity Analysis (O)	✓	✗	✓	✗	✓	✗	✗	✗	✗
3.5	Risk Analysis (✗)	✓	✗	✓	✗	✗	✗	✗	✓	✗
4.	Ecologically									
4.1	Emission Balancing									
4.1.1	CO2 (✓)	✓	✓	✓	✓	✗	✗	✗	✗	✗
4.1.2	Other (O)	✓	✗	✓	✓	✗	✗	✗	✗	✗
4.2	Life Cycle Assessment (✗)	✗	✗	✗	✗	✗	✗	✗	✗	✗
5.	Output									
5.1	Detailed Generation Profile (✓)	✗	✓	✓	✓	✓	✓	✓	✓	✓
5.2	Cash Flow (✓)	✓	✗	✓	✓	✓	✗	✗	✗	✗
5.3	Technical Summary (O)	✓	✓	✓	✓	✓	✗	✓	✗	✗
5.4	Economic Summary (O)	✓	✓	✓	✓	✓	✗	✓	✗	✗
5.5	Ecologic Summary (O)	✓	✓	✓	✓	✓	✗	✗	✗	✗
5.6	Customer Report (O)	✓	✗	✓	✓	✓	✗	✗	✗	✗

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