MODULAR SPECIFICATION OF LARGE-SCALE SOLAR THERMAL SYSTEMS FOR THE IMPLEMENTATION OF AN INTELLIGENT MONITORING SYSTEM

A. Dröscher[1], P. Ohnewein[2], M. Y. Haller[1], R. Heimrath[1]

[1] Institute of Thermal Engineering, Graz University of Technology
Graz, Austria; email: angela.droescher@tugraz.at

[2] S.O.L.I.D. Gesellschaft für Solarinstallation und Design mbH
Graz, Austria; email: p.ohnewein@solid.at

Abstract

The increasing number of large-scale solar thermal systems and the oftentimes required guarantee for the solar gains have created a demand for 'intelligent' automated monitoring that includes data logging as well as data analysis, failure detection and failure identification. This paper presents the development of a modular framework for the description of large-scale solar thermal systems as a basis for an automated monitoring and failure detection software within a R&D project called 'IP-Solar'. The diversity of solar thermal system configurations has been investigated in a market analysis to evaluate their different characteristics that are crucial for a monitoring system. In the analysis, solar thermal systems in Central Europe with more than 80 m^2 of collector surface have been considered. The market analysis, the development of the modular framework design and the specification procedure are presented within this paper.

1. MOTIVATION

For solar thermal systems with large collector areas (e.g. > 80 m^2), a guarantee for the solar energy yields is often claimed by the investor. This guarantee can usually not be given by the engineering or the operating company without permanent monitoring that identifies failures in the operation and consequential energy losses at an early stage. Today, data logging for a solar thermal system might be automated, but monitoring and failure detection works at least partly manually. For the data analysis a qualified expert is needed which is both time- and cost-consuming.

Several approaches considering monitoring and failure detection for solar thermal systems have been developed in the past. Seven of these methods are compared by de Keizer et al. (2008). The described methods have mainly been developed for application on research and demonstration projects where the criteria for time consumption and consequential costs are not as stringent as for commercial operators who support large numbers of solar thermal systems. The time effort results from the fact that neither the solar thermal systems nor their measurement equipment are standardized and therefore the monitoring procedures are individual for each plant. Besides the missing standardization, the investigated monitoring methods mainly do either have a low automation level or they consider only a part of the whole solar thermal system (usually the solar loop). The Kassel University method (KU-method; Wiese, 2006) is the method that comes closest to the idea of the IP-Solar project. The KU-method is already well-developed concerning the monitoring procedures (algorithms for failure detection and identification) and considers most of the aspects that are relevant for the monitoring task of large-scale solar thermal systems. However, there is still potential to refine its usability and expand its field of application: so far, the KU-method has only been tested on solar thermal systems for domestic hot water preparation and only in scientific projects.

A possibility to increase the efficiency of the monitoring task is to make use of a computer-aided system that supports the user in entering the data needed for the execution of 'intelligent monitoring' procedures.

In this context, the term ‘intelligent monitoring’ refers to the combined activities of automated permanent data logging, data analysis, failure detection and failure identification. Intelligent monitoring reduces the time and personnel costs while providing up-to-date information about the system and its performance.

The R&D project IP-Solar has been raised with the aim to develop an intelligent monitoring system for large-scale solar thermal systems, making use of the know-how and experience of the KU-method. IP-Solar aims for a high automation level and therefore low running costs. It shall neither be restricted to a certain hydraulic configuration of the system nor to a certain manufacturer, installer, or operator of solar thermal systems. Figure 1 shows an overview of the work packages (WP) of the IP-Solar project. Within WP1, a modular framework that considers the needed data for intelligent monitoring of any solar thermal system is developed. The hydraulic configuration, the measuring equipment, sensor positions and the control of the solar thermal system are specified. This description framework is built in a way that it can directly be used in the monitoring software (WP4). The results presented in this paper correspond to WP1.1, 1.4 and 1.5 (Figure 2).

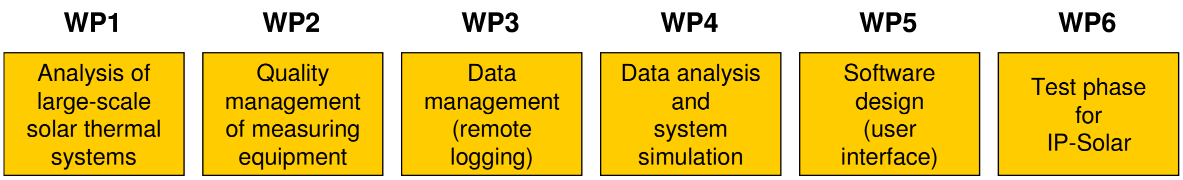

Figure 1. Work packages in the IP-Solar project

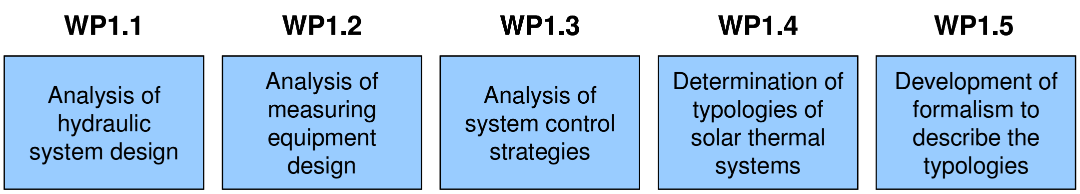

Figure 2. Contents of work package 1

Standardized concepts for large-scale solar thermal systems in Europe have been investigated e.g. by Isaksson et al. (2007) within the European research project 'NEGST'. However, these results can not be employed directly for IP-Solar as the disseminated information is not detailed enough for the analysis in this project. Therefore, an own market analysis was performed within WP1 of IP-Solar. It is presented in section 2 of this paper. The modular framework design for the description of solar thermal system configurations that have been collected with the market analysis is explained in section 3. The specification procedure for the description of the hydraulics as well as the measurement equipment within the monitoring software is outlined in section 4. The discussion is presented in section 5, and section 6 includes the conclusions as well as an outlook on upcoming tasks within the on-going R&D project IP-Solar.

2. MARKET ANALYSIS

A market analysis was performed to identify the most common configurations of large-scale solar thermal systems (>80 m² collector surface) in Central Europe. The characteristics of the investigated configurations serve as a basis for the development of the modular framework that is able to describe a solar thermal system. More than 200 solar thermal systems have been evaluated. Information was gathered from five research projects and reports (Fink et al., 2006; Peuser et al., 2008; Solarge, 2009; Solarkombianlagen-xl, 2009; Stryi-Hipp, 2007) and from four research institutions, six system manufacturers, and two operators of solar thermal systems. Additional information was collected in interviews of experienced associates from the solar industry.

In the future, the IP-Solar monitoring system shall be open for all different configurations of solar thermal systems. However, in order to efficiently get to a first executable version of IP-Solar, the 200 collected solar thermal systems have been sorted out with the following exclusion criteria:

- obvious 'special' applications / niche configurations
- solar cooling applications
- systems with heat distribution with more than one feed and one return line from/to the heat storage
- two or more separate collector loops with independent pump units
- drainbacksystems
- systems with domestic hot water (potable water for most of Europe) filled heat stores
- systems for steam production

The remaining systems (90 plants in total) can be assigned to one of the following fields of application:

1. feeding in a district heat network *(no heat store)* - 2 plants
2. two-line systems *(for both space heating and domestic hot water preparation)* - 39 plants
3. systems for domestic hot water preparation - 49 plants

The main focus at this stage was on the hydraulic design, but also the available information about the measurement equipment and the control strategies has been documented (not shown in this paper) for the upcoming tasks in the IP-Solar project.

3. MODULAR FRAMEWORK DESIGN

In order to be able to execute an intelligent monitoring software, the system hydraulics, the measuring equipment and the control of the system have to be specified in a software interpretable way. The most flexible way to describe the hydraulics of a solar thermal system would be to build it from single components (e.g. heat exchangers and pipes) as it can be done e.g. within the simulation software Polysun (VelaSolaris, 2009) or TRNSYS (Solar Energy Laboratory, 2009)**.** The drawback of this approach is the lack of an ensured technically meaningful context between the components. Mistakes in the specification procedure are hard to prevent or detect. With regard to the automated failure detection and identification within an intelligent monitoring software, the missing predefined context between the single components requires either an automatic procedure (software) that determines the context automatically, or the context has to be chosen manually and verified in the software. The contrary to the single-component-design is to provide models of complete systems where little or no changes in the hydraulic connections can be made. An example for this is the simulation software T-Sol (Valentin, 2009). With this approach, the functional context is fully predefined, but either only simple standard systems can be described or an extensive database that contains the models of the differently configured solar thermal systems is needed. With the single components approach, the user may spend a lot of time connecting the components - with a large potential of committing failures during this process. In the second approach of predefined system hydraulics, the user may spend a lot of time comparing existing system configurations with his plant scheme and may end up not finding one that corresponds to his/her needs.

For IP-Solar, neither one of the two approaches described above was considered to be easy enough to handle and flexible enough for the description of solar thermal systems from all three fields of application mentioned in section 2. Within each of the three fields of application, the hydraulic configuration of the solar thermal system can be realized in different ways. However, irrespective of the field of application, certain parts of the system are essentially the same, e.g. the same solar loop description may be used for a domestic hot water preparation system and for a two-line net system. Therefore, a 'module' can be defined that describes e.g. the solar collector loop, and this module can be used equally for otherwise hydraulic different systems, and even for different fields of application. A 'module' as it is defined within this project represents a unit that may contain several hydraulic components and that fulfils a certain function in the solar thermal system. With this approach, not only the description of the overall system can be built flexibly with a limited number of modules, but also the context of components within each module is conserved and does not have to be determined additionally by hand or by sophisticated software routines. The modular design for the specification of a solar thermal system provides schematic blocks (modules) that describe the hydraulic configuration of a part of the system. These modules can be joined in different combinations to represent a complete solar thermal system. Figure 3 shows an example for a domestic hot water system that is composed of single modules representing the solar loop, charging and discharging of the heat store, the auxiliary heating unit etc. Further modules are listed in Table 1. The boundaries of the modules and the connection points between the modules have been well defined during the module development, assuring unambiguous meaning of connection points and still great flexibility of system design. In Figure 3, the dashed lines represent the module boundaries. The heat store discharging and the heat store auxiliary charging modules are lying upon each other and thus appear to be only one module.

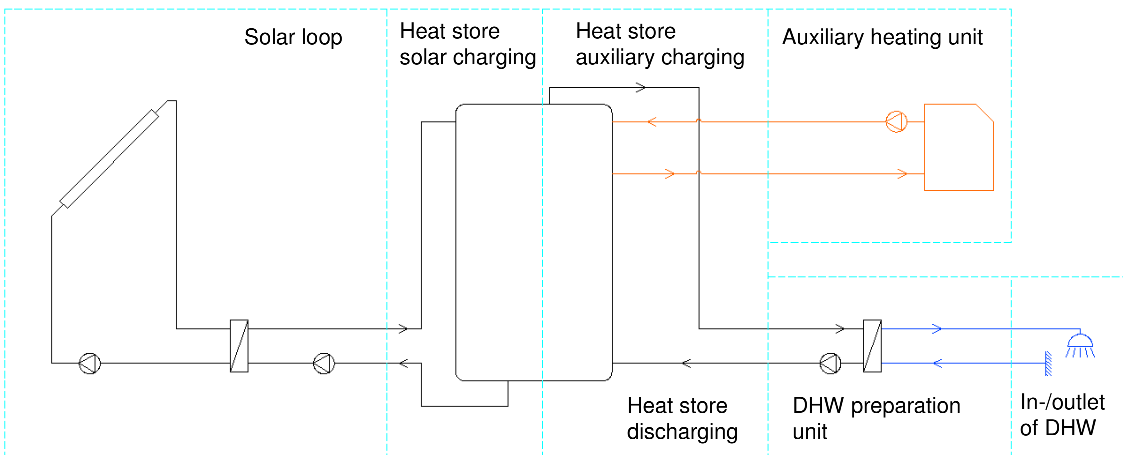

Figure 3. Example solar thermal system built from modules (dashed lines: module boundaries)

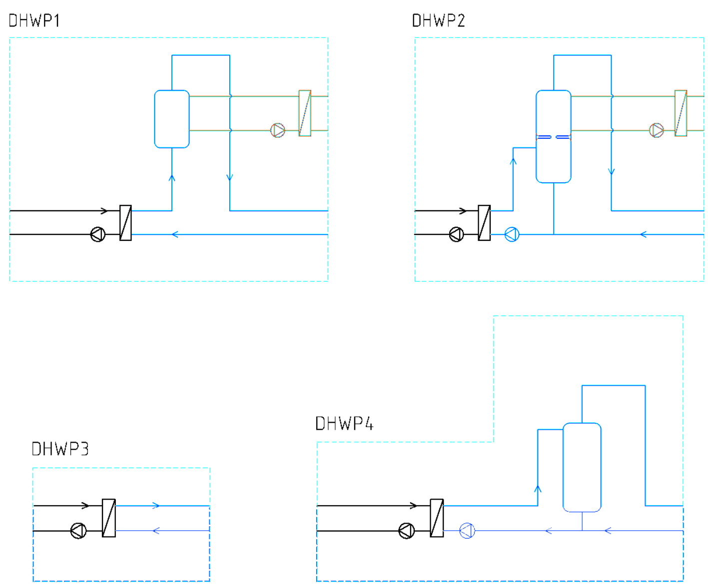

Figure 4. The four variants of module DHWP

Certain functional units (e.g. the domestic hot water preparation unit) can be realized with different hydraulic configurations. Therefore, for each module several "module variants" are specified. That means that every variant of a module fulfils the same function but uses different components and/or assembly. To give an example, the variants of the domestic hot water preparation module are shown in Figure 4. Each variant is identified by the name of the module and a consecutive number.

With the four variants shown in Figure 4, the common configurations of domestic hot water preparation sub-systems are described. However, in many domestic hot water preparation units e.g. a heat exchanger scale protection is installed. This does not change the basic configuration and function of the module, but is rather a simple 'add-on'. For simple add-ons like the scale protection, another lower level in the module structure has been established. Figure 5 gives an overview of the module levels using the example of the DHWP-module and Figure 6 shows detail variants of a module variant schematically.

module level			
module	*module variant*	*detail variant*	*description*
DHWP			module task: domestic hot water preparation
	DHWP1		hydraulic design no. 1 for DHW preparation
	DHWP2		hydraulic design no. 2 for DHW preparation
	DHWP3		DHW preparation in continuous flow principle
		DHWP3a2	detail variant *a2* of DHWP3: scale protection
		DHWP3b2	detail variant *b2* of DHWP3: scalding protection
		DHWP3c2	detail variant *c2* of DHWP3: DHW circulation

Figure 5. Module levels. Example of module DHWP.

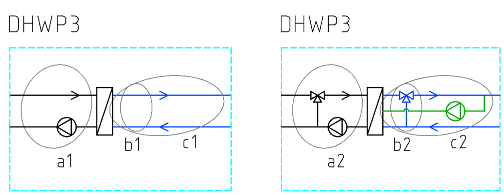

Figure 6. Examples for detail variants of module variant DHWP3

Table 1 gives an overview of the different modules and the number of variants and variant-details that have been defined for each module for the first version of IP-Solar.

Table 1. Number of module variants and detail variants

Module abbreviation	**Module description**	**# module variants**	**# detail variants**
SOL	Solar loop	2	6
HSTS	heat storage tank, solar side	2	3
HSTD	heat storage tank, solar side	3	2
HSTA	heat storage tank, auxiliary heating side	3	6
AUXH	auxiliary heating	4	6
DHWP	domestic hot water preparation	4	32
SINK	heat sink	1	0
DNET	distribution net in a 2-line-net	2	2
DHWIO	DHW input and output	1	0
CDTA	connector module	2	0

4. SPECIFICATION PROCEDURE

When a solar thermal system is specified for the use in the IP-Solar monitoring system, it is assembled by choosing the appropriate modules step by step. Rules that restrict the theoretically possible combinations to the technically meaningful ones have been developed and implemented in the software in order to prevent mistakes made by the user in the specification procedure. At the beginning of the specification procedure, the user of the IP-Solar software always chooses a variant of the solar loop module (SOL), since this module is mandatory for any solar thermal system; the choice of all other modules depends on the particular system configuration. Step by step the user selects the other modules needed for the description of his/her solar thermal system from a list that is given from the software until the solar thermal system is specified completely. The contents of this list is updated after each step, depending on the modules that the user has chosen by then.

The next step after the hydraulic specification procedure is to identify the sensors that will be available for data logging and carrying out the algorithms for data analysis, failure detection and failure identification. The sensors can be chosen from a predefined list that is stored in the IP-Solar software and depends on the modules that have been chosen. Several possible sensor positions have been defined for each module variant based on the results of the market analysis mentioned in section 2. Each sensor position is labelled with a unique name. Depending on the available measurement equipment of a solar plant and the hydraulic context known from the module's description, the software automatically selects the failure detection algorithms that can be executed. However, the user is free to disable certain algorithms.

5. DISCUSSION

The 90 solar thermal systems that have been investigated in detail for IP-Solar have been selected according to exclusion criteria where non-common systems have been discarded innately. However, IP-Solar will be open to extensions that provide the possibility to handle even more different solar thermal system configuration types.

Balancing the advantages and the disadvantages of the different ways of hydraulic system description based on single components and based on complete system schemes, respectively, has led to the modular design that is presented in this paper.
Each module contains components that by means of their function within the solar thermal system belong together. Even if the flexibility of the modules is shortened in comparison to individual components, still a wide variety of solar thermal systems (all 90 plants that served as a basis for the modularization) can be described. It is not realistic that solar thermal systems in the future are subjected to design standards - there will always be special applications that cannot be easily described with simple standardized modules. Those special applications still can employ the IP-Solar monitoring system and monitor at least those parts of the solar thermal system that fit the predefined modules. Furthermore, configurations that look different at first sight may be treated in the same way with respect to automated monitoring. However, if a certain plant component (e.g. an adsorption chiller) becomes a widely used “technique” on the market, the modular framework of IP-Solar allows for extensions and inclusion of new modules.

In the market analysis, the differences in the measurement equipment have been observed to be even bigger than the differences in the hydraulic configurations. For the development of a monitoring system it has to be taken into consideration that the options for monitoring a solar thermal system are strongly dependent on the measurement equipment (both quantity and positioning of the sensors as well as their quality). Therefore, the modules have been prepared to embed different configurations of measurement equipment.

6. CONCLUSIONS AND OUTLOOK

It has been found that for common applications of large-scale solar thermal systems it is possible to describe different hydraulic configurations using standardized modules. The use of standardized modules makes it easier to employ an automated monitoring system whereas the particular configuration of the monitoring system is strongly dependent on both, the hydraulic system configuration and the available measurement equipment.

The next step in the project is to develop a recommended minimum measurement equipment for every module, based on the same market analysis where not only the hydraulic configuration but also the measurement equipment of large-scale solar thermal systems has been evaluated. Finally, algorithms that allow for automated monitoring and failure analysis will be developed based on the available measurement equipment.

At its highest stage of completion, the monitoring system will include a feature to compare the measured performance data of the solar thermal system with the results of a TRNSYS-simulation that will equally be based on the modular description presented in this paper (de Keizer et al., 2009).

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