COLLECTION AND ASSESSMENT OF AVAILABLE FUNCTION AND YIELD CONTROL CONCEPTS AND DEVICES FOR LARGE SOLAR THERMAL SYSTEMS

TR 5.2.1

Institut für Solarenergieforschung GmbH Hameln/Emmerthal (ISFH)

Klaus Vanoli

Am Ohrberg 1
D-31860 Emmerthal
Tel. +49 (0) 5151/999-100, Fax -500;
www.isfh.de

TZSB / IZES

Danjana Theis

Fraunhofer ISE

Wolfgang Striewe

In cooperation with:

AEE INTEC – Institute for Sustainable Technologies

Philip Ohnewein

Version: 2.0

Date: 25/05/2012

Final Document

Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

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1 Introduction, remarks and first analysis

This chapter contains introductory remarks on the scope of this status report and a first analysis of the material submitted by the actively contributing QAiST participants, and has been compiled by the leader of Subtask 5.2.

1.1 Scope of this status report on FYC devices and concepts

In the first workplan for QAiST Subtask 5.2 "Function and Yield Control for large solar thermal systems" it was decided to form a team of EU-wide experts in FYC amongst the project partners, who are ready to actively cooperate in this subtask.

The following authors of the active participants listed in Chapter 1.2 compiled their knowledge on those FYC methodologies, in which they are actually involved in or in which they have been involved in during preceding R&D projects:

- Dr.-Ing. Klaus Vanoli, ISFH, Hameln, Germany
- DI Danjana Theis, TZSB / IZES, Saarbrücken, Germany
- DI Wolfgang Striewe, ISE, Freiburg, Germany
- DI Philip Ohnewein, AEE INTEC, Gleisdorf, Austria

It was agreed upon reporting in a standardized format in order to facilitate the comparison and later analysis in view of the elaboration of a QAiST FYC summary describing the actual state of the art.

Thus, for each of these FYC methodologies (stated as "FYC Item"), an own Chapter has been set up by the authors mentioned above, giving 7 nearly identical chapters of this present report.

The responsibility for each chapter lies with the author stated in the section "Source of Information".

Additional contributions are planned from ISE, Freiburg on their research about innovative volume-flow-meters, and from IZES, Saarbrücken on their on-going research about FYC Items for large solar thermal systems, where positive experiences from their presented FYC Items on small solar systems will be exported to larger systems.

1.2 Actively contributing members of the QAiST working group on Function and Yield Control

- **Institut für Solarenergieforschung GmbH (ISFH)**

Klaus Vanoli
Arbeitsgruppe Thermische Systeme
Am Ohrberg 1
D-31860 Emmerthal
Phone: +49 (0)5151/ 999 – 525
Email: k.vanoli@isfh.de; k.vanoli-hameln@t-online.de

- **Test Centre for Thermal Solar Systems (PZTS)**

Wolfgang Striewe
Fraunhofer Institute for Solar Energy Systems (ISE)
Heidenhofstraße 2
D-79110 Freiburg
Phone: +49 (0)761/ 4588 - 5354
Email: wolfgang.striewe@ise.fraunhofer.de

- **TZSB der IZES gGmbH**

Danjana Theis
Hochschultechnologiezentrum (HTZ)
Altenkesseler Str. 17, Geb. D2
D-66115 Saarbrücken
Phone: +49(0)681/5891-831
Email: theis@izes.de

- **AEE INTEC – Institute for Sustainable Technologies**

Philip Ohnewein
Feldgasse 19
A-8200 Gleisdorf
Phone: +43 (0) 3112 5886-255
Email: p.ohnewein@aee.at

1.3 Quick overview of the reviewed systems

This quick overview has been elaborated for the 1st QAiST Meeting in Munich, in June 2010. A subsequent actualization took place for the final report in May 2012.

It is clear, that the collected information reflects only the FYC status in the countries of the actively contributing QAiST participants, i.e. Austria and Germany. So this report does in no way reflect an EU wide FYC overview and the presentation of FYC items in this report is not the result of any selection process other than the decision of QAiST participants to actively contribute to Subtask 5.2 or not.

Table 1 gives a quick overview on the reported FYC Items according to their scope (FC resp. FYC), their state of development and their market availability, separately for small and larger systems.

Table 1: Synopsis of reported FYC methods and products

	Function control		Function and yield control	
	Research	Marketed	Research	Marketed
Small systems	FUKS FAUSOL	SONJA SUNGO	IOC	RESOL IOC Bosch
Large systems	FUKS*		IP-Solar IOC Uni Kassel**	RESOL IOC Web-IOC

* Some algorithms suitable for large solar thermal systems

** Project started 2010

Additional differentiations are needed in the future, e.g. according to

- the control boundary: solar loop only / solar and auxiliary heat supply;
- status of availability: research & development / commercialized item.

For example, IP-Solar is the only FYC item which actually aims on whole systems control, including the subsystem for auxiliary heat supply. But for the time being, this item is still in the research area. Internal tests with IP-Solar have been carried out at SOLID in 2011 showing the proof of concept.

The IOC FYC item is to our actual knowledge the only marketed item; it is commercially available at two partner companies, who reported briefly on their products in Chapters 6 and 7. The IOC devices are operating also with small solar thermal systems, although their main application domain is large solar thermal systems because of an improved cost/benefit relation.

As stated earlier, additional contributions are planned from:

- Fraunhofer ISE, Freiburg on their research about innovative volume flow meters, and from
- IZES, Saarbrücken on their on-going research about Items for large solar thermal systems, where positive experiences from their presented FYC Items on small solar systems will be exported to larger systems.

1.4 Web-Search for existing FYC surveys beyond QAiST project

Because of the rather low participation level of QAiST members, and the resulting lack of EU-wide representation of other available FYC concepts, ISFH conducted a fast web-search for existing FYC Surveys outside of the QAiST project. As a result, two reports on FYC surveys were found:

- "Quality assurance in large solar thermal systems": a report from F. Brandstetter, Arsenal, Wien, published in 30/2009 by bmvit, the Austrian Ministry for Traffic, Innovation and Technology about results of the Q-SOL Project [1]
- "Overview of Monitoring and Failure Detection Approaches for Solar thermal Systems", a literature analysis from A.C. de Keizer, University of Kassel, published in Proceedings Eurosun 2008 [2]

The following two sections give a short summary for each of the two reports found.

1.4.1 Brandstetter Report

Chapter 6.2.1, pages 72 - 81 describes the following FYC approaches:

- In-Situ-Short-Term-Testing-Verfahren (ISTT) for solar yield rating and commissioning (Source: ZAE Bayern)
- Input-/Output analysis for FC (Source: arsenal research)
- Input-Output-Controller (IOC) for FC and solar yield rating (Source: ISFH, Hameln)
- automatized long-term supervision of Kassel University (Source Univ. Kassel)
- standardized systems optimization and FC in scientific monitoring project OPTISOL (Source: AEE INTEC)

- standardized solar yield rating and FC of solar warm-water pre-heating systems in France (GRS TECSOL, Perpignan)

On the basis of a detailed discussion of these approaches, Brandstetter comes to the following conclusions:

- there are interesting approaches in development, but the awareness and dissemination are very low.
- manually operating approaches are not well suited
- performance and accuracy are good for some automatized concepts, but many systems are still too expensive
- only the IOC approach has reached status of commercialization, giving hope to future cost reduction, especially if integrated into building automatization concepts.

1.4.2 A.C. de Keizer overview

Within an extensive literature study at University of Kassel, the following FYC approaches have been identified:

- Manual monitoring with the example of the Optisol Project (MM)
- Function control for small solar thermal systems without heat measurements (FUKS)
- Input-Output Controller (IOC)
- Guaranteed Solar Results (GSR)
- Method developed at Kassel University (KU)
- Spectral method (SP)
- Failure detection with Artificial Neural Networks (ANN)

The results a multi-criteria-analysis conducted by A.C. de Keizer are summarized in Table 2 within a FYC performance matrix.

A.C. de Keizer summarizes the results of her analysis and concludes with the following text (citation):

“The IOC is the first method which could result into the implementation of a monitoring and failure detection method into general use of larger solar thermal systems. It has been tested and is commercially available against a reasonable price, but it does not apply to the whole solar system. Manual monitoring, though more costly, is much easier adapted to extensive variation in hydraulics and systems.

Table 2: Synopsis of reported FYC methods and products (Source: A.C. de Keizer, Univ. Kassel, 2008

Criteria	*MM*	*FUKS*	*SP*	*IOC*	*ANN*	*GRS*	*KU*
Automatic failure detection included?	--	++	++	++	++	--	++
Automatic failure identification included?	--	+	--	+-	--	--	+
Accuracy of failure detection	++	+-	?	+	?	+-	+
Accuracy of failure identification	++	+-	n.a.	+-	n.a.	n.a.	+-
Costs (operational/hardware)	-- var	++ 100 €	+?	+ 1190 €[1]	+?	-- 10 k€[2]	+- 20-80€[3]
Monitored part of solar heating system (so far)[4]	var	sl	sl	sl, bs	sl	-aux	-aux

Qualitative scale: ++ yes/very good/cheap via +- = reasonable to -- no/very bad/expensive
? = unclear

[1] IOC: only hardware
[2] costs for measurement equipment, including one year monitoring
[3] Costs per month for 20 year monitoring and at least 30 monitoring systems sold. The main costs are expected for maintenance and improvement of software (between € 15 and 50 per month) [11].
[4] var = variable, sl = solar loop, -aux = whole system besides auxiliary heating system, bs = buffer discharging loop (optional for IOC)

The method developed at Kassel University is still in development, but could also provide an automatic monitoring solution for large systems. It includes more sensors and a larger part of the system than the IOC approach, and can therefore also analyse individual components. For very small systems the approach followed in FUKS detects several failures at reasonable additional costs.

However, so far none of the above described approaches takes the auxiliary heating system into account, which is also an important source of errors.

Conclusion, discussion and outlook

An overview of methods for monitoring and failure detection has been presented in this paper. Several differences are highlighted by means of a partial multi-criteria analysis. The results are presented in a performance matrix, in which the methods are qualitatively evaluated with certain criteria. Quite a few methods are in an (advanced) stage of research and development, this complicates the analysis of the functioning of the different approaches. The Input/Output Controller, Guaranteed Solar Results and Manual monitoring can already be applied in commercially built solar thermal systems. Of those, the Input/Output controller is the only one that analyses the measurement data automatically and provides an automatic failure indication.

However, none of the approaches include the auxiliary heating system. Several approaches, e.g. the method from Kassel University, are being developed further to increase the ability of detection and identification of failures. Furthermore practical experience has to be gained for a better evaluation of the performance of several approaches."

1.5 Analysis of the actual FYC status as of June 2010

As a first result of the present analysis, the two FYC survey studies carried out by AIT, Austria and by Kassel University have obviously selected a rather similar set of the FYC cases to be treated and compared.

Thus it may be concluded, that these FYC cases form a rather complete set of FYC methodologies actually available in Europe.

According to both of the survey studies, the most promising FYC approaches for a wide-spread use in large solar thermal systems are:

- the Kassel University / IP-SOLAR Projects, and
- the IOC concepts.

Both FYC items are treated in the present report.

Hopefully, additional FYC concepts still in R&D level and presented in this report will become available soon for first practical testing.

As a combined conclusion of both survey studies and our own experience, the following topics have to be treated with great effort in the future:

- continued R&D is needed for the implementation of function and yield control capabilities of whole systems aspects including auxiliary heat supply subsystems;
- market introduction of available FYC concepts and devices;
- build-up of practical experience in the field in combination with FYC training programmes;
- implementation of FYC into technical guidelines and standards.

Especially the last three items have to be approached together with all involved parties of the solar thermal systems market.

In order to stimulate the next steps, a proposal for a strategic discussion of the future development of the FYC technology together with "Recommendations for Further Needed Activities in FYC" has been elaborated and presented in technical report **TR5.2.2**.

2 Function and Yield Control (FYC) item: IZES #01

2.1 Knowledge base

2.1.1 Source of Information and responsible author of the Chapter

IZES gGmbH

Dipl-Ing. (FH) Danjana Theis

Altenkesseler Str. 17, Geb. A1

D - 66115 Saarbrücken

+ 49 (0) 681 - 9762 - 840

tzsb@izes.de
www.izes.de

2.1.2 Own involvement to FYC item

Preparation of FMEA (Failure Mode and Effect Analysis) and development of fault detection algorithms.

Validation of two controller prototypes with implemented fault detection algorithms at a small solar domestic hot water system.

2.1.3 Date and status of development

First prototypes were involved in 1999. Two participating companies (*Wagner&Co Solartechnik, Cölbe* and *esaa GmbH Innovative Solartechnik, Mühlacker*) had implemented the fault detection algorithms in their controllers. In 2010 the controllers are still on the market. Additional functions were added to the prototype status (for different types of small solar domestic hot water and space heating systems). The research activity has been terminated.

2.1.4 Availability

The project "Funktionskontrollen bei kleinen thermischen Solaranlagen ohne Wärmemengenerfassung" was funded by DBU (Deutsche Bundesstiftung Umwelt). Reference number is "14291". The fault detection algorithms are freeware and the project report is available via IZES gGmbH (handling fee 10,- €).

The control items (*SONJA, esaa GmbH* and *SUNGO, Wagner Solartechnik*) are commercialized and in property of the participating companies.

2.1.5 Supplemental Information and publications

Final project report: Altgeld H., Mahler M, Schuster F., Theis D., Final project report: Funktionskontrollen bei kleinen thermischen Solaranlagen ohne Wärmemengenerfassung - FUKS, Entwicklungsprojekt der DBU, AZ: 12281, Juli 1999

Project summary: Altgeld H., Forschungsbericht der HTW - Funktionskontrollen bei kleinen thermischen Solaranlagen ohne Wärmemengenmessung, 1999

Project presentation: Mahler M., Vorstellung des FUKS-Projektes auf der AK-Norm Sitzung, 30.11.2004

Publications: H. Altgeld, T. Bischoff, M. Mahler, F. Schuster, D. Theis, Funktionskontrollen bei kleinen thermischen Solaranlagen ohne Wärmemengenmessung, 9. OTTI-Symposium Thermische Solarenergie, 1999

2.2 Scope and category of control item

2.2.1 Scope

The verified control items within this project had function control ability. Additional to that a method for the determination of the flow rate on basis of temperature flanks and pipe content was verified. A cheap heat flow measurement and yield control is possible with this additional feature.

The verified control items can be used in small solar thermal systems. Commercialized control items with similar fault detection characteristics are available for large systems.

2.2.2 Short description / category of control item

The fault detection algorithms can be implemented in standard control-devices.
The commercialized control devices have different fault detection possibilities depending on the number and types of additional installed sensors. A limited number of faults can be detected with the standard temperature sensors of a difference temperature controller. A yield control is possible, if the necessary sensor informations are provided.

Different control applications (beside of fault messages on the controller display) are possible depending on the configuration of the control item.

2.2.3 Stakeholders i.e. main target user group

The main target group are end users. Based on the fault messages of the control items, the installer or manufacturer of the system can be informed.

2.3 Applicability of control item to solar system type and size

2.3.1 Anticipated system size

During the project the fault detection algorithms were verified at a SDHW-system with $A_{col} = 5\ m^2$ in the test lab. Additional field tests were performed at medium sized solar thermal systems $A_{col} > 10m^2$. Most of the fault detection algorithms can be adapted to larger systems, $A_{col} > 50m^2$. The current possibilities and range of the further developed function control items are available from the manufacturers.

2.3.2 Solar system type

The function control items are used in the following systems (with different function detection possibilities):

- Solar Domestic Hot Water systems with single storage tanks;
- SDHW systems with two storage tank;
- Combined SDHW and space-heating systems;
- Combined SDHW, SH and swimming pool heating systems.

2.3.3 Description of subsystems controlled, control delimitation, control boundary

The collector loop, parts of the storage tanks (temperature sensors, heat exchanger characteristics) and the controller itself are controlled by the fault detection algorithms. An additional irradiance monitoring is possible, depending on the configuration of the control item.

2.4 Hardware and software description of control item

2.4.1 Electronics and sensors

Two different control items were developed with different configurations. The basic function is already assured, if the control item has two temperature sensors (T_{coll}, T_{sto_bottom}) and a timer function. More faults are detected with an additional pressure sensor, an irradiance sensor and a flow meter. A yield control is possible too, if the respective sensors are implemented.

The commercialized items have different options for data storage, data transfer and remote application.

The controllers (*SUNGO S, SUNGO SL, SUNGO SXL*) from *Wagner Solartechnik GmbH&Co* provide the following functions (depending on their configuration):

- data logging via DATAstick;
- remote control via DATAstick (in preparation);
- alarm messages via DATAstick (in preparation);
- modem interface via DATAstick (in preparation);

The controllers (SONJA SR5, SR20, SHR40, SHR60, SHR70, SHR80) from esaa Böhringer GmbH provide the following functions (depending on their configuration):

- data transfer to PC via serial interface;
- H-Bus digital interface;
- remote control;
- alarm messages via H-Bus digital interface.

2.4.2 Description of control algorithm, control logic

The control algorithms are implemented in the solar controllers. The detailed descriptions of the algorithms are available in the project report. The following system faults can be detected (state of the project report), **Error! Reference source not found.**.

Table 3: System fault detection with FUKS algorithms

Fault No.	Fault description	Necessary information
1	Switched collector inlet and outlet	T_{col}, Time
2	Collector temperature sensor misplaced	T_{col}, Time
3	Leakage of solar heat exchanger	p_{col}
4	Scaled solar heat exchanger	T_{sto_Bottom}, T_{hx_i}, T_{hx_e}, G (or volume flow)_
5	Primary pressure of expansion vessel too high	p_{col}
6	Primary pressure of expansion vessel too low	p_{col}
7	Cut-off valve closed	T_{col}, T_{sto_Bottom}
8	Cable break between controller and pump	T_{col}, T_{sto_Bottom}
9	T_{col} damaged or inaccurate	
10	T_{sto_Bottom} damaged or inaccurate	
11	Controller outputs	T_{col}, T_{sto_Bottom}, Time
12	Controller inputs	T_{col}, T_{sto_Bottom}, Time
13	Controller Software	T_{col}, T_{sto_Bottom}, Time
14	Wrong flow rate	T_{col}, T_{sto_Bottom}
15	Air in solar loop	T_{col}, T_{sto_Bottom}
16	Open non-return valve	T_{col}, T_{sto_Bottom}, Time
17	Polluted non-return valve	T_{col}, T_{sto_Bottom}, Time
18	Wrong settings of difference temperature controller	T_{col}, T_{sto_Bottom}
19	Wrong setting of internal Timer	Time
20	Power cut	
21	External current anode defect	

2.5 Status of development

2.5.1 Practical experience

The manufacturers of the control items have practical experience since 1999. The number of installed control items and detected faults are available via the manufacturers.

2.5.2 Commercialization

The control items are commercialized since 1999. More information is available via the manufacturers.

2.6 Warranty concepts

Based on the function and yield control items different guarantee concepts are possible. More information is available via the manufacturers.

2.7 Commissioning tests

Currently no information available

3 Function and Yield Control (FYC)-Item: IZES #02

3.1 Knowledge base

3.1.1 Source of information and responsible author of the Chapter

IZES gGmbH

Dipl-Ing. (FH) Danjana Theis

Altenkesseler Str. 17, Geb. A1

D - 66115 Saarbrücken

+ 49 (0) 681 - 9762 - 840

tzsb@izes.de
www.izes.de

3.1.2 Own involvement to FYC Item

Development of a checklist and a PC-software for fault detection and diagnosis of small solar domestic hot water systems.

3.1.3 Date and status of development

The software was developed as part of the EU-project "FAUSOL-Fault Detection and Diagnosis Tool for Solar Domestic Hot Water Systems"

The project and the research activity were finished in 2000.

3.1.4 Availability

The project was funded within the ALTENER programme. The results and check list are both freeware and available via IZES gGmbH.

The developed software was tested under MS Windows 95-98 systems and is not functional in combination with modern operating systems.

3.1.5 Supplemental information

Final project report: Altgeld H., Mahler M, Schuster F., Theis D., Final project report: FAUSOL-Fault Detection and Diagnosis Tool for Solar Domestic Hot Water Systems, ALTENER project No. 4.1030/Z/97-149

Fausol Checklist: "FAUSOL Fehler-Erkennungs- und Diagnose-Toolfür kleine thermische Solaranlagen, FAUSOL PAPER - Papierversion 1.0 "

Publications: H. Altgeld, M. Mahler, D. Theis, FAUSOL - Fault Detection and Diagnosis Tool for Solar Domestic Hot Water Systems, 10. Symposium Thermische Solarenergie, Kloster Banz 2000

3.2 Scope and category of control item

3.2.1 Scope

Software and checklists for fault detection and diagnosis of small solar domestic hot water systems

3.2.2 Short description / category of control item

A Software tool based on Visual Basic 6 and/or a checklist is delivered to the user or installer of a solar hot water system. Based on this up to 74 faults can be detected.

3.2.3 Stakeholders, i.e. main target user group

The main target group are end users. Based on the results of the Software or the checklists, the installer or manufacturer can be informed.

3.3 Applicability of control item to solar system type and size

3.3.1 Anticipated system size

The Software and Checklists cover only small SDHW-systems with $A_{col} < 10$ m². Parts of the checklists can be extrapolated to larger Systems

3.3.2 Solar system type

Only SDHW-systems

3.3.3 Description of subsystems controlled, control delimitation, control boundary

All parts of the SDHW systems are covered by the Software or the checklists, including auxiliary heater and drinking water supply and circulation.

3.4 Hardware and software description of control item

3.4.1 Electronics and sensors

No additional electronics or sensors are required.
The fault detection and diagnosis tool is based on a Visual Basic 6 Software.

3.4.2 Description of control algorithm, control logic

The fault detection can be performed shortly after installation of the system of if there are any doubts in the functionality of the system

3.5 Status of development

3.5.1 Practical experience

During the validation phase 29 end users and manufacturers has tested the Software. The results were taken into account for the further development of the Software until the end the project in 2000.

3.5.2 Commercialization

The software and the checklists are not commercialized.

3.6 Guarantee concepts

The tool cannot be used within guarantee concepts

3.7 Commissioning tests

The tool can be used shortly after installation of a SDHW-system as a function control instrument.

4 Function and Yield Control (FYC) Item: AEE INTEC / S.O.L.I.D. #01

METHODIQA / IP-SOlar

4.1 Knowledge base

4.1.1 Source of information and responsible author of the Chapter

AEE INTEC – Institute for Sustainable Technologies

Feldgasse 19, 8200 Gleisdorf, Austria

Philip Ohnewein, p.ohnewein@aee.at,

Phone +43 (0)3112 5886-255

Fax: +43 (0)3112 5886-18

www.ip-solar.com

4.1.2 Own involvement in FYC item

Own development: S.O.L.I.D. has been coordinating all activities regarding IP-Solar within an interdisciplinary consortium. While IP-Solar has ended, the work started in IP-Solar is being reformulated in another national Austrian R&D project (starts end 2012) under the name “METHODIQA” lead by Philip Ohnewein, AEE INTEC and including the main project partners who also worked on IP-Solar.

4.1.3 Date and status of development

IP-Solar has been under development since May 2008. Internal tests at SOLID in 2011 have shown the basic proof-of-concept. As mentioned above, the project “METHODIQA” will further extend the scientific basis and the scope of the method.

At the time this report is written, the most recent publication about the methodology and the state of development of this FYC item is:

- Ph. Ohnewein, A. Dröscher, K. Schgaguler, F. Feichtner, E. Meißner, P. Luidolt, A. Köstinger, R. Heimrath, M. Jaindl, W. Streicher: ‚IP-

Solar: Development of a Web-Based Monitoring and Diagnostics Tool for Solar Thermal Systems'. Eurosun 2010, Graz, Austria

This paper can be downloaded free on www.ip-solar.com.

4.1.4 Availability

IP-Solar will be available to customers as a commercial software tool. It will remain property of the developing parties with licenses offered to customers.

Patents: IP-Solar has no patents pending, and will very probably never have any patents pending. The core technology is protected by the centralized design.

4.1.5 Supplemental information

For information about the ongoing activities for this FYC item, contact the project coordinator Philip Ohnewein (see above for details).

- The current research activities within the project "METHODIQA" will start end 2012. So far, the latest information about the closed project IP-Solar can be found on www.ip-solar.comextensive information in English and German
- All scientific publications relating to IP-Solar are available online.

Since the most recent activity "METHDIQA" will only start end 2012, all information following in this chapter refers to the closed project IP-Solar.

4.2 Scope and category of control item

4.2.1 Scope

Scope: data acquisition and storage, function control, yield control and failure and yield analysis, automatic notification in case of failures, access via internet platform.

4.2.2 Short description / category of control item

IP-Solar is a monitoring, function and yield control software tool. Its design is central, so basically no extra peripheral hard- or software is necessary. Also, no measuring equipment must obligatorily be available at the solar plant.

Inside IP-Solar, a detailed failure detection analysis based on several classes of diagnostic algorithms is performed. The algorithms differ in terms of complexity; they range from a simple calculation of important key figures (e.g. specific solar energy yield per day / month / year) up to self-learning algorithms that automatically adjust to a plant's behaviour.

Also, in case some unwanted behaviour is detected in the solar installation, IP-Solar will provide the user with a quick and specific notification by SMS or email. The information sent out includes very specific information about the kind and location of failure and identification of failure causes if possible.

The diagnostics, evaluations and algorithms are run on a centralized server which also collects the measuring data of the monitored plants. The server also runs an internet platform accessible to the users of IP-Solar.

For details about the described features, see below.

4.2.3 Stakeholders, i.e. main target user group

IP-Solar is aimed at several target groups.

This is based on the IP-Solar multi-layer user design: each target group will get tailored information by IP-Solar. This means that – on one end – scientific institutions will have insight into tiny details of the monitoring and diagnostic kernel, while – on the other end – a public funding body or end-user of a plant will get a quick graphical overview of the plant's key figures.

The main target user groups of IP-Solar are the end-users of a solar installation and its operators, but also scientific institutions involved in monitoring activities and public institutions like e.g. funding authorities.

4.3 Applicability of control item to solar system type and size

4.3.1 Anticipated system size

IP-Solar is mainly aimed at large systems with a collector area of more than 50 m². This is due to the failure detection algorithms which are tailored to the standardized hydraulic configurations typically found in medium to large installations.

In principle, it is possible to extend IP-Solar's functionalities to smaller systems, though a few adaptations would be necessary.

4.3.2 Solar system type

IP-Solar uses a specific modular approach to model the hydraulic configuration of a solar plant in the software.

It is possible to construct your own plant's configuration based on the single modules. In this way, a wide variety of system types can easily be controlled by IP-Solar. For example, all typical DHW configurations for larger solar systems can be chosen as modules. Process heat or 2-line-systems are other options.

Furthermore, the modules can be customized to exactly map the plant's details. For example, stratified charging of the tank storage in various heights may be chosen as a detail.

Inside each module, the measuring equipment and sensors present in the installation can be chosen and assigned properties such as sensor type etc.

This information is subsequently used for automatic error propagation analysis.

4.3.3 Description of subsystems controlled, control delimitation, control boundary

The following sub-systems are part of the IP-Solar analysis:

- collector loop with pump unit(s) and external heat exchanger;
- storage tank (if present), with different options for charging of the tank, integration of the auxiliary heating, etc.;
- different types of auxiliary heating;
- different types of DHW generation configurations;
- distribution net (from storage to decentralised consumers, e.g. for local heating nets).
- general heat sink (e.g. for process heat, district heating, etc.)

Decentralized home stations are outside the system boundaries.

Other sub-systems such as heat pumps or solar cooling configurations are currently not included in IP-Solar, but may be added in the future following the modular approach described above.

From the view of measurement equipment, a very wide variety of user-installed sensors are taken into account in the plant monitoring and in the failure analysis. These include temperature sensors, pressure sensors, irradiance sensors, heat meters, volume flow sensors, etc.

However, there is no compulsory measurement equipment for IP-Solar. Rather, IP-Solar has the ability to include all available sensors into the ongoing analysis and failure diagnosis.

Examples of different options for the auxiliary heating module are given in Figure 1 and **Error! Reference source not found.**.

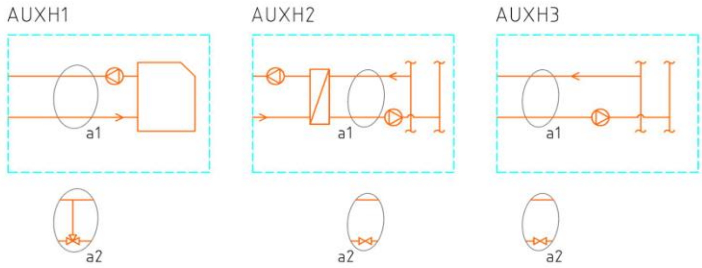

Figure 1: Example of different options for the auxiliary heating module

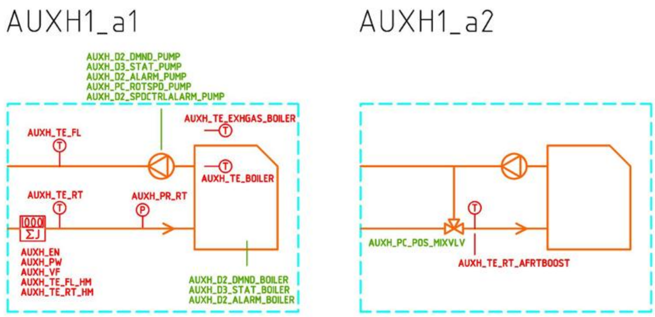

Figure 2: Example of two auxiliary heating module possibilities including the standardized IP-Solar data points and their positions

4.4 Hardware and software description

4.4.1 Electronics and Sensors

IP-Solar is a software tool for fully automatic solar plant monitoring. In this case, the term monitoring also includes aspects such as data acquisition and long-term storage, yield control, a very thorough failure check and notification of users in case of unexpected behaviour.

The behaviour of IP-Solar in all these aspects is highly and easily customizable. The IP-Solar design is suitable for modelling numerous common types of large solar plants.

The IP-Solar software runs on a central server, so basically, no extra peripheral hardware or software installations are necessary on site. The central IP-Solar server includes the database, it permanently processes the diagnostics in quasi real-time on a powerful CPU and it runs the IP-Solar internet platform

The data acquisition is adaptable to individual requirements (see below for more details). The only requirement to the plant's control system is the capability to send or let IP-Solar retrieve the ongoing measuring data via an Ethernet connection. As most control system suppliers nowadays offer some sort of Ethernet module for their own control equipment, IP-Solar can work with virtually all important control system suppliers.

The control equipment present at the solar plant needs not be adapted in order to let IP-Solar work; rather, IP-Solar can understand virtually any data format provided these systems and converts it to a standardized internal IP-Solar data format.

Besides the data transfer, no adaptations are necessary at the installations in order to make IP-Solar work. In terms of measuring equipment and sensors, the requirements on the customer-side measuring instrumentation are rather low. IP-Solar automatically adapts its diagnostics capabilities to the existing measuring concept. So, while there is no compulsory measuring equipment required by IP-Solar, a concept for "minimum recommended measuring equipment" has been developed in the course of the project for all sub-systems / modules. This recommended measuring equipment includes those sensors and sensor locations within the plant that are essential for most failures to be detected.

In the case IP-Solar detects some unwanted system behaviour; the users are notified via email or SMS. The notification system is described below.

4.4.2 Description of control algorithm, control logic

IP-Solar is a software tool for automatic solar plant monitoring. In this case, the term monitoring also includes aspects such as data acquisition and long-term storage, yield control, a very thorough failure check and notification of users in case of unexpected behaviour.

The whole IP-Solar diagnostic system runs in a fully automated way requiring no user interaction. The only non-automated steps occur once, at the beginning, when a new solar plant is added to IP-Solar. Adding a new plant typically takes no more than a few hours.

Figure 3: Basic workflow of the IP-Solar method. Source: www.ip-solar.com

The behaviour of IP-Solar in all these aspects is largely and easily customizable. The IP-Solar design is suitable for modelling numerous common types of large solar plants.

The basis for the IP-Solar diagnostic capabilities has been developed based on a very thorough analysis of possible failures in solar installations. This analysis includes failures in system parts such as auxiliary heating, domestic hot water generation and obviously solar circuit, storage tank etc. IP-Solar incorporates a fully automatic error propagation analysis taking to account the accuracy and current values of the measuring equipment installed in the plant. Moreover, the IP-Solar diagnostics procedure is rather flexible and can be adapted to suit the user requirements of each solar plant

The diagnostics, evaluations and algorithms are run on a centralized IP-Solar server which also collects the measuring data of the monitored plants. Measuring data can be imported into the IP-Solar database in quasi real-time for any plant; this includes advanced data filtering methods. Subsequently, failure detection algorithms are performed on the new data. For important failures, such as a critical temperature sensor exceeding its maximum permitted security temperature, the failure check is performed every minute. This means that users get notified about important failures within a very tight timeframe. The notifications settings are largely customizable and comprise email and SMS messages.

Users take advantage of the IP-Solar functionality by the notifications and reports sent out by the system on one hand. On the other hand, users can access IP-Solar via a web interface with any browser. There, all key figures, monitoring data and information about failures are prepared in detail for further analysis and may also be printed and downloaded. So, IP-Solar combines several advantages: There is no distributed software, but the web-based design makes IP-Solar easy-to-use and maintenance-free for users. All information and plant evaluations are available at any internet-connected PC.

On the IP-Solar internet platform, users can change personal settings and adjust the graphic representations of results. All key fig-ures and monitoring data are prepared in detail for further analysis and may also be printed and downloaded.

As to the programming language, IP-Solar is programmed in different languages depending on the different needs of the system. These languages include Java, C and php / AJAX. All collected measuring data can be transmitted to IP-Solar via an encrypted connection. On the IP-Solar server, these data are protected by state-of-the-art IT security measures. All data are stored in the central IP-Solar database on a long-term basis.

4.5 Status of development

4.5.1 Practical experience

In the course of the R&D project, the IP-Solar diagnostic tool is being tested with 3 pilot plants located in Graz. The pilot plants are commercial installations and have 3 different hydraulic configurations, so the functionality for a wider variety of plants is being examined.

The 3 pilot installations are of types ‘hot water generation’, ‘2-line-system’ and ‘district heating supply’.

4.5.2 Commercialization

IP-Solar will be available on the market in the form of software licenses to several target groups such as end-users, plant operators, scientific institutions and public bodies in the future.

Based on the currently available information, IP-Solar will fulfil the main definitions of the new German VDI 2169 [3].

4.5.3 Further development

The new Austrian R&D project “METHODIQA” (starts end 2012) will go deeper into the FYC methodology and extend its analytical power. From a system’s point of view, an additional focus will be set on biomass and the combination of renewable and non-renewable heat technologies. The main objective still remains the automation of the FYC process.

4.6 Warranty Concepts

IP-Solar will show numerical and graphical comparisons of the plant’s solar energy yields compared to the guaranteed output per month and per year. However, IP-Solar detects many of the possible failures or malfunctions leading to energy yields below the guaranteed ones on a daily basis.

From a juridical point of view, there is another interesting feature to point out: one of the benefits of IP-Solar is the comprehensive documentation of the behaviour of a solar installation. This is possible due to the long-term storage of plant data and results in a central database. This means that for any future legal questions, all necessary data will be available for all IP-Solar controlled installations with high availability.

4.7 Commissioning tests

As the diagnostic methodology of IP-Solar is very profound and thorough, also a variety of engineering or design errors will be detected by IP-Solar. In this sense, IP-Solar affects not only the operating phase, but also the engineering and commissioning phase.

Also, as the functionality of IP-Solar depends on the accuracy of the installed measurement equipment (just like with any other FYC item), the correct calibration of sensors in the commissioning phase improves the diagnostic capabilities of the underlying algorithms.

5 Function and Yield Control (FYC) item: ISFH #01

5.1 Knowledge base: Input/Output Controller Technology (IOC)

5.1.1 Source of information and responsible author of the Chapter

Institut für Solarenergieforschung GmbH (ISFH)
Solar Thermal Systems Group
Am Ohrberg 1
D-31860 Emmerthal
Dr.-Ing. Klaus Vanoli
Phone: +49 (0)5151/ 999 – 525
Phone: +49 (0) 170 83 295 78
Email: k.vanoli@isfh.de
www.isfh.de

5.1.2 Own involvement to FYC item

The IOC-Technology and the IOC-Procedure have been conceived by ISFH and developed in close cooperation with several partner Companies up commercially available IOC-Devices by the conpanies RESOL GmbH, Hattingen and INGA GmbH, Hameln.

Intensive tests of IOC-devices in more than 35 solar systems during the last ten years have proven both the control-accuracy as well as the practicability in the solar HVAC application.

5.1.3 Date and status of development

The establishment of the scientific and technological basics of the Input/Output procedure is the result of a research project funded by the German Federal Ministry (BMU) from 1999 – 2007.

Commercial availability since 2008 for stand-alone and web-based IOC devices; see Chapter 6 and 7 for more details.

5.1.4 Availability

ISFH as holder of the IOC patent right has declared to DIN, that ISFH is willing to negotiate licences under reasonable, non-profit-making and non-discriminatory terms and conditions with applicants throughout the world. Information may be obtained from ISFH, see Chapter 5.1.1.

5.1.5 Supplemental Information:

The final report (in German) of the research project funded by the German Federal Ministry (BMU) from 1999 – 2007 for the development and validation of the IOC-Procedure will be sent to you by mail request.

Some English summary-reports are in the annual reports 2004-2006: http://isfh.de/institut_solarforschung/jahresberichte.php

Further information is available under:

http://isfh.de/institut_solarforschung/publikationen.php

Publications:

Pärisch P., Blumentritt F., Vanoli K.,Synetrum, Experiences, Technologies and Strategies in the Field of Modern Quality Control of Solar Thermal Output: 1st IOC-User Meeting, Workshop Solarhaus Freiburg im Rahmen der EUROSUN 2004, ISES DGS, Freiburg, Deutschland, Juni, 2004.

Pärisch P., Vanoli K. Ertragssicherung mit dem ISFH-Input/Output-Verfahren. Prinzip, Modellierung, Verfahrensunsicherheit, Tagungsbericht 16. Symposium Thermische Solarenergie, Kloster Banz, Bad Staffelstein, 17.-19.5.2006

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(OTTI), Regensburg (Hrsg.),, 368-372, Staffelstein, Deutschland, April, 2002

Vanoli K., Pujiula F., Der neue IOC-Algorithmus: „Von der täglichen Nutzbarkeitsbestrahlung zum Erwartungswert des Kollektorertrags“, 13. Internationales Sonnenforum, Berlin, 12.-14.9.2002, Tagungsband, Deutsche Gesellschaft für Sonnenenergie e.V. (DGS), 120-121, Berlin, Deutschland, September, 2002

1Vanoli K., Pujiula F., Garantiert(e) Solare Wärme! Die ISFH/IOC-Technologie als Meilenstein auf dem Weg zur solaren Gewährleistung, 1. Architekten- und Ingenieurstagung im Rahmen der SOLAR ENERGY 2002, 13.-14.6.2002, Tagungsband, Technologiestiftung Innovationszentrum Berlin, Berlin, Deutschland, Juni, 2002

Vanoli K., Pärisch P., Funktionskontrolle solarthermischer Systeme durch Ertragsbewertung, Brennstoff-Wärme-Kraft-online (eBWK), Springer VDI-Verlag, 60, 1-8, Düsseldorf, Deutschland, Januar/Februar, 2008

5.2 Scope and category of control item

5.2.1 Scope

Function and Yield Control by the IOC procedure are provided by a fully automatized rating (resp. valorisation) of the daily solar yield, by performing a comparison of the actually measured yield with a simulated yield, which is predicted on the basis of the actual conditions of irradiation, ambient temperature and load, taking into account the performance and control parameters of the solar and conventional components installed.

A retrospective Yield analysis is possible by the use of associated ioc-software-tools, permitting the re-calculation of the actual yield with modified performance parameters, using the recorded high-resolution measuring data of the period of interest.

5.2.2 Short description / category of control item

Two differently operating IOC-Devices have been developed and are commercially available today:

- Stand-Alone IOC-Devices (see Chapter 6 for further details of the RESOL IOC-Device);
- IOC-WEB-Server-based Controlling System (see Chapter 7 for further details of the INGA IOC-WEB-Service system).

5.2.3 Stakeholders, i.e. main target user group

Function and Yield Control by means of IOC has been tailored to both parties of the solar thermal market: the supply side and the investor side

Planning engineers, builders and installers will profit from:

- initial optimization;
- improved commissioning based on yield data;
- guaranty of system operation and solar system yield;
- quality marketing;
- protection against unjustified yield claims.

Users, operators and investors will benefit from:

- verification of guarantied collector yield;
- quality monitoring of the solar system;
- Operation-Check- and Verification of predicted Solar Yield;
- Protection against undetected Solar System Breakdown.

Additional parties of interest are e.g. scientific institutions as well as funding agencies.

5.3 Applicability of control item to solar system type and size

5.3.1 Anticipated system size

Due to the fundamental scientific basis of the IOC algorithm, there are no limitations for the use of IOC-Devices regarding the collector size of a given solar thermal installation. Up to now, practical experience is available for collector areas ranging from 2 to about 300 m² of collector surface.

If economic criteria are additionally taken into account, then the use of IOC-devices is recommended for collector surfaces greater than 20 to 2 m² due to the improved cost / benefit relation.

5.3.2 Solar system type

The IOC-Devices can be applied to a multitude of solar systems, meeting the following criteria:

- collector array with one collector type and shade-free orientation (i.e. identical collector performance parameters);
- solar-systems with one heat sink (i.e. one typical solar-to-load-temperature);
- no thermosiphon systems;

- solar loop with internal or external heat exchanger;
- direct solar loop (e.g. drain-back systems, solar pool heating).

Practical experience is available for solar pool heating, DHW systems, solar combisystems, solar district heating.

(if there is more than one storage tank, see Chapter 6 or Chapter 7 for additional detailed information)

5.3.3 Description of subsystems controlled, control delimitation, control boundary

The IOC-procedure has been developed with two alternatives for the measurement position of the daily solar energy yield, thereby defining two different control boundaries:

The solar yield measurement position in IOC procedure Type I is situated at the outlet of the solar loop circuit; the corresponding sensors are shown in Figure 4. The controlled solar yield corresponds to the solar loop output.

The solar yield measurement position in IOC-procedure Type II is placed at the outlet of the buffer tank discharge loop circuit; the corresponding sensors are shown in Figure 5. Here the control boundary is rather near to the net solar system yield.

5.4 Hardware and software description of control item

5.4.1 Electronics and sensors

IOC devices are commercially available today as:

- Stand-alone IOC devices (see Chapter 6 for further details of the RESOL IOC device)
- IOC Web-server based controlling system (see Chapter 7 for further details of the INGA IOC Web-service system)

Both types of IOC devices need a local hardware for measuring / data acquisition and data storage.

Stand-alone IOC devices are additionally equipped with a data processing unit and CPU for the implementation and the continuous execution of the IOC algorithm (see Chapter 5.4.2.). According to the specific IOC hardware specifications, resulting data and messages are stored, displayed and/or transferred to appropriate remote signalling devices (e.g. alarm signals, automatic phone dialling units). The local data processing unit and CPU is further more equipped with a non-volatile memory-unit for password protected storage of the solar systems parameter file. In future, Stand-alone IOC devices may be combined with standard solar controllers.

In IOC Web server based controlling systems, the IOC algorithm is run continuously on a remote server, where he receives the high-resolution site-specific measurement data on a day-by-day basis for centralized procession. The server handles furthermore the parameter file for each supervised solar system as well as customer oriented transfer of IOC-results, messages and alarm-signals.

The following figures (Figure 4

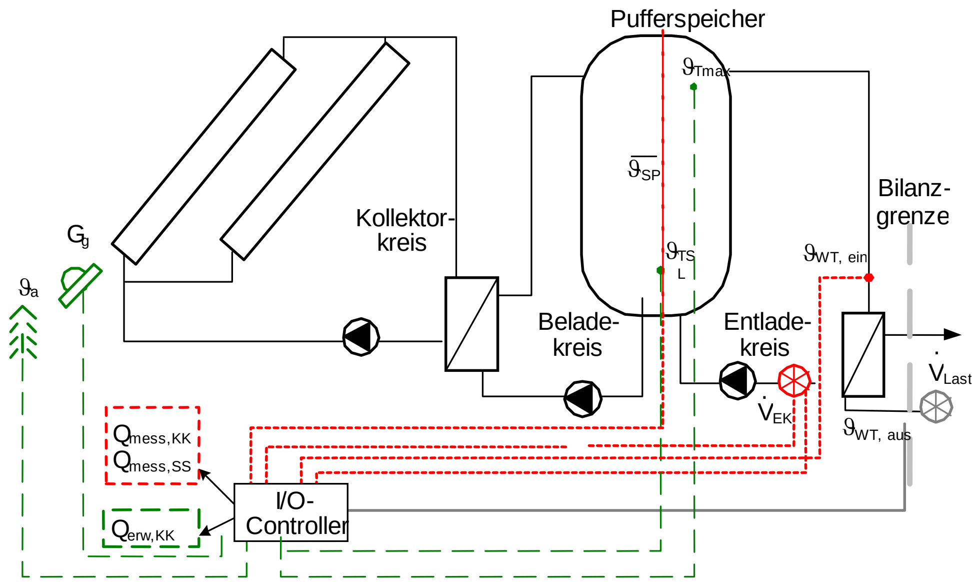


Figure 5 show the measuring system and required sensors:

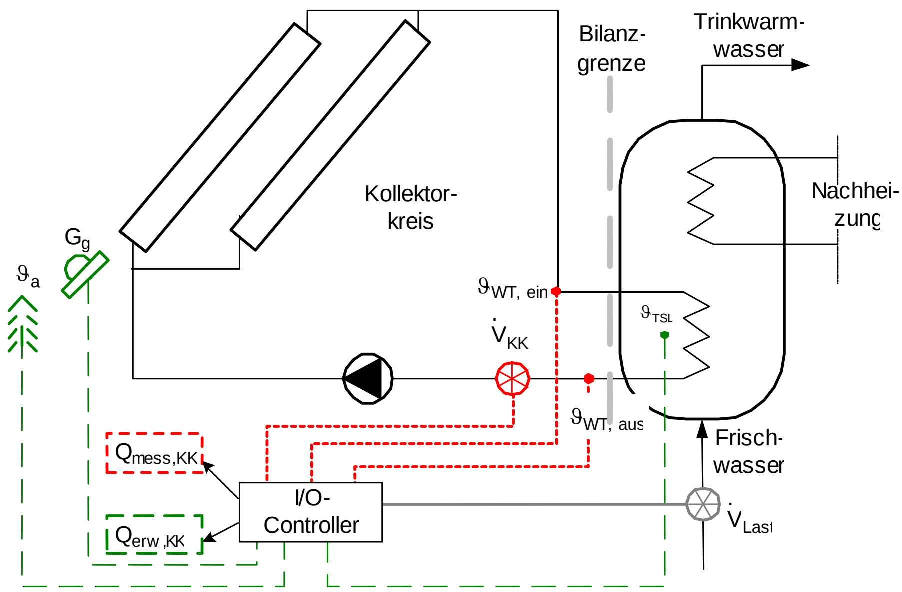


Figure 4: Control boundary at the outlet of the solar-loop in IOC procedure Type I

![QAiST logo]

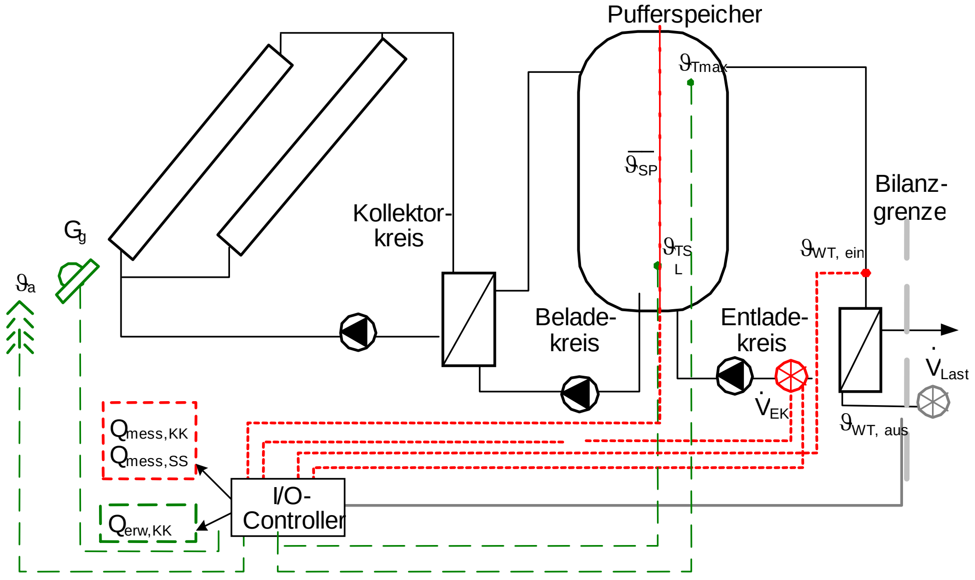


Figure 5: Control boundary at the outlet of the buffer tank discharge loop circuit in IOC procedure Type II

5.4.2 Description of control algorithm, control logic

The core function of the IOC algorithm is independent from its location or implementation into a stand alone or in an IOC WEB-server system.

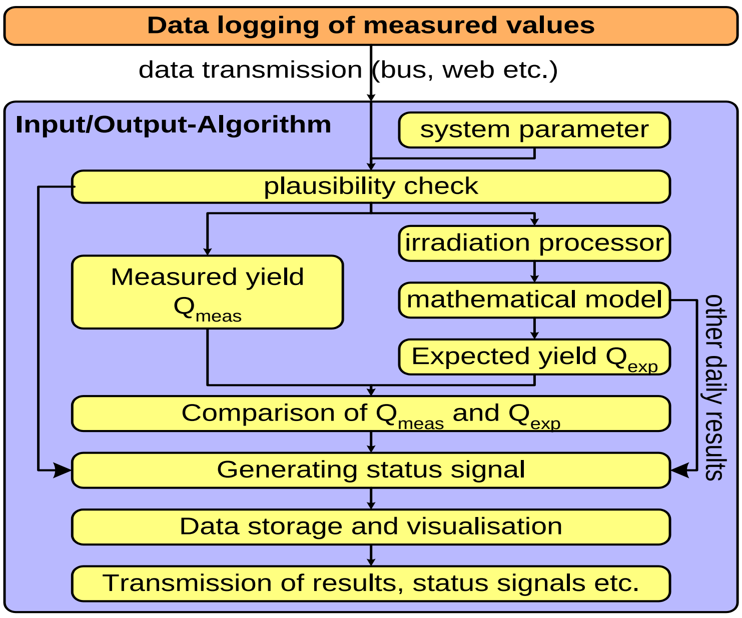


Figure 6: Flow schematic of the IOC algorithm

The Input/Output algorithm is implemented in control units or run on servers:

- At first, measured data and parameters are checked for plausibility.
- Then measured and expected yield are calculated using different sensors and parameters. The irradiation processor splits the global irradiance G_g into diffuse and direct to determine the absorbed radiation.
- The expected yield Q_{exp} is simulated with measured data of irradiance G_g, ambient air temperature J_{amb}, typical solar load temperature J_{TSL} and the high limit cut-off temperature? ΔT_{max}. Furthermore the I/O controller has to know up to 40 parameters of the solar system (e.g. collector efficiency coefficients like zero loss coefficient and heat loss coefficients, collector tilt and azimuth angle, collector area).
- The J_{TSL} describes the temperature of the heat sink of the collector loop, i.e. a (buffer) storage tank, a return of a district heating system etc. The advantage of using the J_{TSL} is that the same mathematical model can be taken for the collector loop of all kinds of systems.
- At the end of the day, the deviation of Q_{meas} and Q_{exp} is interpreted and a status signal is generated automatically. The tolerance is set to the triple standard uncertainty of the Input/Output procedure (apr. 7 %). This has been determined by a sensitivity analysis considering both, the uncertainties of parameters and measurement.

The programming language of the IOC algorithm is only the choice of the manufacturer. Once a solar system is initialized, the day-by-day execution and generation of IOC result data, messages and warnings is fully automatized. The only non-automated steps are the initial parameterisation and the reset of the error-message once an error message has led to the repair of the system.

Thus, frequency and personnel resources bound to the non-automated steps are directly linked to the data refresh interval for solar-yield tracking, which depends on each operator’s requirements.

Table 4: Type of automatically detectable errors / malfunctions

Code	*Messages/warnings/failures*	Code	*Messages/warnings/failures*
1	OK	8	*Low-load-Warning caused by low-load & exceeding Tmax*
2	*Too-high-yield*	9	*Low-yield-Warning caused exceeding Tmax*
3	*Too-low-yield due to solar failure*	10	*Incomplete-data or sensor-signal out of bounds* Sensor malfunction

4	*Too-low-yield due to storage-discharge failure*	11	*Volume-flow-rate-error*
5	*Primary-pump-operation too long*	12	*Low-load-Warning caused by low-load & normal Tmax*
6	*Over-sized-Warning caused by exceeding Tmax*	13	*Night-time-primary-pump-operation*
7	*Negative-yield_ check for param*	14	Low-yield and Snow / frost message

Availability of fault diagnosis

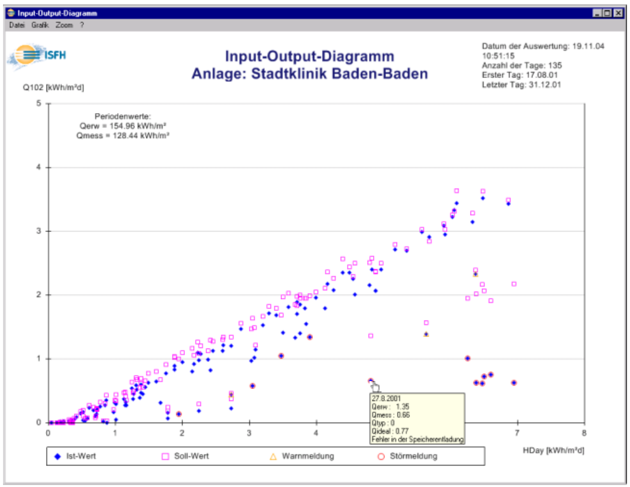


Figure 7: Input/Output diagram data for a hospital in Baden-Baden, Germany, 2001

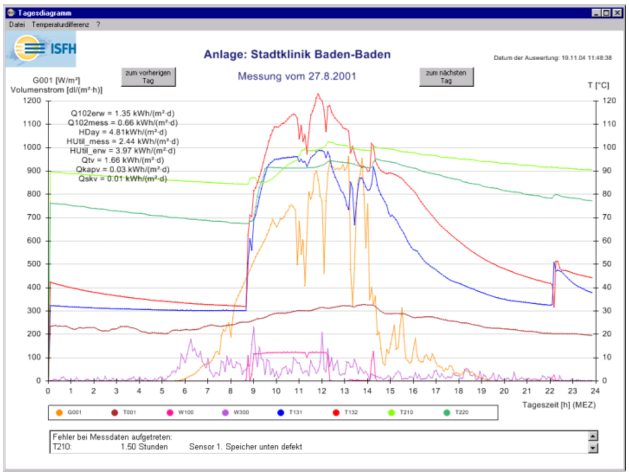


Figure 8: Daily high resolution measurement showing failure in storage discharge of a hospital system in Baden-Baden, Germany (27.08.2001)

The IOC-Service-software "IOC-KLICK" generates automatically Input/Output-Diagrams with the typical linear relationship of daily solar yield as a function of daily irradiation. A mouse klick on the diagram shown in Figure 7 for the measured low-yield day of 27.08.2001 generates the 5-Minutes data diagram (Figure 8) for that specific "failure"-day, showing clearly the slow temperature decrease of 2 of the 3 the storage tanks: the upper one of the two green lines cools down from 90°C at midnight to 85°C at 09:30, the lower one goes down from about 77°C to 68°C, without any temperature-decay due to the high warm water load between 05:30 and

07:30). The origin of that error has been caused by the blocked heat-exchanger in the dis-charge look of the storages.

This example of IOC-Fault-handling is given here as a demonstration for the complexity of fault-diagnosis: in most situations, time-series of measurements and/or derived quantities, are in no way directly assigned to just one cause of the failure, in most situations the information available about errors are more than ambiguously related to a multitude of possible failures. In the present example, a blocked dirt-trap or a broken discharge pump could have caused the same temperature time-series in the buffer tanks.

Detailed information about optimization of the plant/system

Using stored high resolution data of the IOC-Devices, and the IOC-Service-software "IOC-KLICK", you can perform retrospective solar-yield calculations with parameter variations in the parameter file of your system. E.g. varying the heat transfer factor of the solar loop heat exchanger from 25 %, 50 % 75 %, you might compare these "new" expected yields with what you measured.

5.5 Status of development

5.5.1 Practical experience

Number and sizes of plants/systems:

- above 30 systems are equipped with IOC-devices
- system size ranges from 2 m² up to 286 m²

Experience since:

- 2001

Detected major faults:

- all faults of Table 4
- no system without failures
- additional failures: inverse thermosiphon in collector loop
- (automatic detection of inverse thermosiphon still in progress, needs separate treatment of "forward- und backward- thermosiphon flow!)
- strange hydraulic errors

Influence on system yield:

- factor of yield reduction 100 % (no yield at all in case of failure)
- frequently factor of yield reduction 15 to 40 % in case of bad system design / system layout / system size

5.5.2 Commercialization

Implementation in the market:

- see Chapter 6 and Chapter 7 of cooperating IOC companies
- ISFH ready to negotiate further licence agreements
- cooperating housing company has committed to equip all future SDHW systems with IOC devices.

Recognized control item for GSR surveillance:

In the view of ISFH: We see IOC perfectly suited for a fully automated GSR surveillance. The "expected yield model" inside the IOC algorithm has been carefully validated against both measured system yield as well as TRNSYS simulations. The deviation of about 7,6 % is in perfect agreement with a thorough analysis of the combined un-certainty of IOC-measurement sensors and the required IOC parameters.

5.6 Warranty Concepts:

See remark in Chapter 5.5.2

5.7 Commissioning tests

IOC-devices are perfectly well suited for commissioning tests of solar thermal systems. Yield improvement during commissioning by 15 to 35 %

5.8 Additional topics

Housing company uses yield reports for justifying the energy saving effects of solar investments.

6 Function and Yield Control (FYC) item: RESOL #01

6.1 Knowledge base: RESOL Input / Output Controller

6.1.1 Source of information and responsible author of this Chapter

RESOL GmbH
Heiskampstr. 10
D-45527 Hattingen
Dipl.-Ing. Guido Filler
Phone: +49 (0)2324 / 96 48 0
Email: guido.filler@resol.de
www.resol.de

6.1.2 Involvement in the FYC item

As hardware-partner of ISFH in the BMU R&D Project for the IOC-Development, RESOL has played the lead role in developing a Stand-Alone-IOC-Device

6.1.3 Date and status of development

RESOL Input / Output Controller is commercially available since June 2007.

6.1.4 Availability

See Annex I for further information.

7 Function and Yield Control (FYC) item: INGA #01

7.1 Knowledge base: INGA-IBS IOC-Web-Server

7.1.1 Source of Information and responsible author of this Chapter

INGA Ingenieurgesellschaft für Gebäudeautomation mbH
Wehlerweg 14
D-31785 HAMELN
Dipl.-Ing. Horst Zacharias
Phone: +49 (0)5151/ 94 51 0
Email: z@inga-hameln.de
www.inga-hameln.de

7.1.2 Own involvement in the FYC item

As hardware-partner of ISFH in the BMU R&D Project for the IOC-Development, INGA has played the lead role in developing an IOC-WEB-Server Technology

7.1.3 Date and status of development:

INGA-IBS_IOC-Web-Server is commercially available since April 2008

7.1.4 Availability:

See Chapter 7.1.1 for further information

7.1.5 Supplemental Information:

See Annex II for further information

8 Update on FYC concepts, May 2012

8.1 Function and Yield Control (FYC)-Item: University of Kassel

8.1.1 Knowledge base

8.1.1.1 Source of information and responsible author of the Chapter

Stefan Küthe, Reza Shahbazfar, Klaus Vajen
Kassel University
Institute of Thermal Engineering
Kurt-Wolters-Str. 3
D - 34125 Kassel
Email: solar@uni-kassel.de
www.solar.uni-kassel.de

8.1.1.2 Involvement in the FYC-Project

Preparation, development and validation of methods and algorithms for fault detection and fault diagnosis for small scale, medium size and large scale solar thermal systems. Implementation of a data management system to handle the huge amount of measurement data accruing within the project.

8.1.1.3 Date and status of development

The Project started in June 2011. Today, a data management system is implemented receiving data from several solar thermal systems. Within the data management system different data formats from different solar thermal systems are automatically parsed and stored into a central database. Besides the automatic data processing, methods and algorithms are developed. By the end of the project in 2014, further methods and algorithms will be introduced. Today, demonstration plants are being installed where faults can be generated manually and the methods and algorithms can be tested.

8.1.1.4 Market availability

The project "Entwicklung, Untersuchung und Anwendung von Methoden zur Langzeitüberwachung und automatisierten Fehlerdetektion großer solarunterstützter Wärmeversorgungsanlagen" is funded by BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit). The reference number is 0325975A.

The data management system is located at Kassel University. After the research project the results will be published. The developed methods and algorithms can be implemented into market available controllers. It is planned to develop a new independent long term monitoring service for large scale solar thermal systems, based of the developed data management system.

8.1.1.5 Supplemental information

Publications:

Keizer, C., Küthe, S., Vajen, K., Langzeitüberwachung für Großanlagen: Datenbank, Algorithmen und Simulation. VDI-Solarkonferenz Heizen und Kühlen mit der Sonne, Ludwigsburg, 27.-29.09.2011, VDI-Berichte 2152, pages 125 ff.

R. Shahbazfar, A.C. de Keizer, S. Küthe, U. Jordan, K. Vajen, Universität Kassel, Fehlerdetektion und Fehlerdiagnose für große thermische Solaranlagen, 2012, Tagungsband des 22. OTTI Symposium Thermische Solarenergie, pages 40 ff.

de Keizer, A., Vajen, K., Jordan, U., Review of long-term fault detection approaches in solar thermal systems. Solar Energy Journal Volume 85, Issue 7, July 2011, pages 1430-1439

Küthe, S., Keizer, A.C. de, Shahbazfar, R., Vajen, K., Implementation of data processing and automated algorithm based fault detection for solar thermal systems, Proc. ISES Solar Word Congress, 28.08. - 02.09.2011

Shahbazfar, R., Entwicklung eines algorithmenbasierten Konzepts zur automatisierten Funktionsüberwachung thermischer Solaranlage, Masterarbeit, Institut für thermische Energietechnik, Universität Kassel, 2011

8.1.2 Scope and category of the project / product

8.1.2.1 Scope

The scope of this research project is to develop methods and algorithms for function control of solar thermal systems. Under investigation are small scale, medium size and large scale solar thermal systems. Available information of the auxiliary heater will be included. Different levels of complexity are under consideration, starting from simple controller implemented methods to more sophisticated methods running on a powerful server including dynamic system simulations.

8.1.2.2 Short description / category of the project / product

After the research project, the developed methods and algorithms shall be implemented into market available controllers and a server based independent long term monitoring service shall be provided.

8.1.2.3 *Stakeholders i.e. main target user group*

The main target groups are manufactures and system providers, receiving detailed messages in case of system failures. The advantage for end users is detailed information about their solar thermal system. In addition, in case of simple faults, an emergency program can be started.

8.1.3 Applicability of the method to solar system type and size

8.1.3.1 *Anticipated system size*

There is no limitation in system size.

8.1.3.2 *Solar system type*

Any pumped solar thermal system may be included, whereas a minimum number of sensors is required.

8.1.3.3 *Description of subsystems controlled, control delimitation, control boundary*

In the focus are mainly the collector loop, heat exchangers, storage, as well as the auxiliary heating system.

8.1.4 Hardware and software description

8.1.4.1 *Electronics and sensors*

Fault detection algorithms will be developed for different kinds of sensor sets. The accuracy of fault detection is related to type and number of installed sensors. On the lowest level only a few temperature sensors are used, whereas on higher levels additional sensors like pressure, volume flow or irradiation sensors offer possibilities to detect further faults.

In case of remote server based fault detection, the submission of data should be done automatically. Typically, this it is done by a logger or controller via a mobile network connection. Error messages or warnings can either be send by the logger (depending on the hardware) or by the server as emails or SMS.

8.1.4.2 *Description of control algorithm, control logic*

For the algorithms different approaches are used depending on the installed sensor sets. A detailed description will be given in the final report. The algorithms can be implemented in the controller or will run on a remote server.

8.1.5 Status of development

8.1.5.1 *Practical experience*

At the moment there is practical experience in the field of the data submission and storage. Also algorithms have been developed and tested successfully.

8.1.5.2 Commercialization

A commercialization will be done typically by the manufactures implementing algorithms in their devices. Additionally an independent service for a remote function control of solar thermal systems might be offered.

8.1.6 Warranty concepts

Based on the function and yield control items different guarantee concepts are possible. More information is available via the manufacturers.

8.2 Function and Yield Control (FYC)-Item: Bosch Thermotechnik GmbH #01

The description of the product is based on the poster presented at the 22. OTTI Symposium on Solar Thermal Energy in Bad Staffelstein, May 2012.

8.2.1 Contact person for the product

Dr. Werner Hube
Bosch Solarthermie GmbH
(TT-STT/ESY)
Prozessionsweg 10
48493 Wettringen
GERMANY
www.bosch-solarthermie.de

8.3 Short description of the product

The new system controller was developed for an advanced fault detection and fault handling of simple and complex solar thermal systems.

Function control is based on a constant evaluation of the sensor signals. Algorithms developed for signal evaluation allow a fault detection of typical failures in classic solar thermal systems (Figure 9a):

Temperature sensor:

- wrong sensor type or sensors switched
- sensor placed wrongly
- sensor damaged

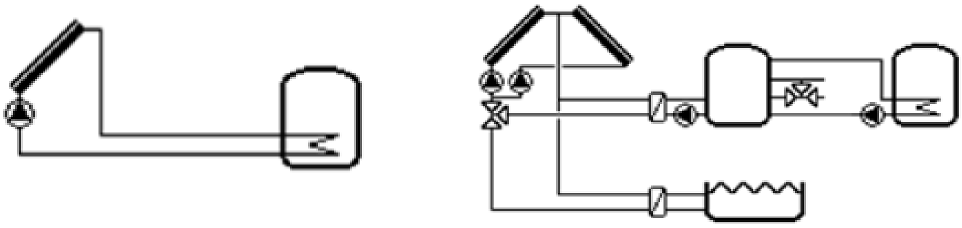
No circulation:

- air in system
- pump blocked

Fault detection of more complex systems (Figure 9b):

Systems with more storages:

- switched storage temperature sensor
- wrong switch logic
- switched collector temperature sensors if more collector fields installed
- sensor control on external heat exchanger



(a) (b)

Figure 9: Typical system configurations of solar thermal systems – classic configuration (a) and complex configuration (b)

An important product feature is the failure treatment. If a failure is detected, the control algorithm tries to compensate the failure by implementing alternative control strategies, as far as possible. The advantages of this feature are:

- the system continues with the operation, if possible
- solar yield in spite of failure
- transfer of system information to smart phones
- quick failure elimination possible by active communication

Besides the fault diagnosis, the system is capable of providing yield determination of the solar thermal system, which can transmitted to the smart phones.

For the system characterisation, a short parameterisation time after the installation is needed for the control unit to automatically analyse the obtained data. No additional measurement equipment is needed.

A poster (in German) from the 22. OTTI Symposium on Solar Thermal Energy in Bad Staffelstein, is shown in Annex III.

References

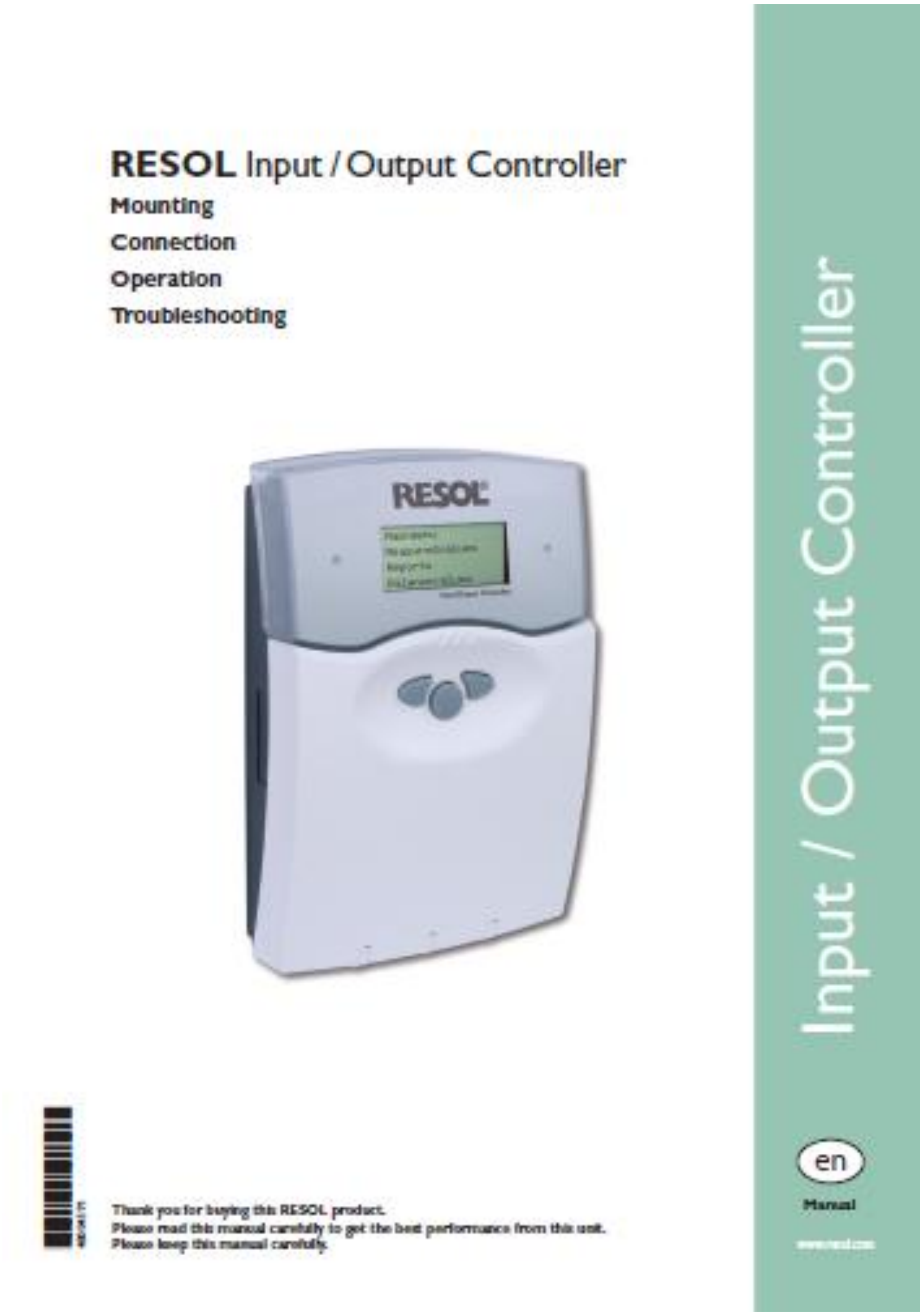
[1] Brandstetter, F.: Qualitätssicherung solarthermischer Großanlagen: Qualitätssteigerung und Qualitätssicherung großer thermischer Solaranlagen in gebäudeübergreifenden Mikronetzen und im großvolumigen Geschoßwohnbau. Bundesministerium für Verkehr, Innovation und Technologie, Schriftenreihe 30/2009, "Berichte aus Energie- und Umweltforschung". Wien, 2009

[2] de Keizer, A.C.: "Overview of Monitoring and Failure Detection Approaches for Solar thermal Systems", University of Kassel, published in Proceedings Eurosun 2008, International Solar Energy Society (ISES) Europe, (ID 376), Lissabon, Portugal, (2008)

[3] VDI Guideline VDI 2169 „Funktionskontrolle und Ertragsbewertung bei solarthermischen Anlagen", Gründruck, VDI-Gesellschaft Bauen und Gebäudetechnik (Hrsg), Beuth Verlag, Berlin (developed since 2004, availabe as green-print since 2010, final white-print announced for summer of 2012)

![QAiST logo]

Annex I: RESOL Input / Output Controller



RESOL Input / Output Controller

Mounting

Connection

Operation

Troubleshooting

Thank you for buying this RESOL product.
Please read this manual carefully to get the best performance from this unit.
Please keep this manual carefully.

Input / Output Controller

en

Manual

Input / Output Controller

RESOL®

Safety advice

Please pay attention to the following safety advice in order to avoid danger and damage to people and property.

Appropriate usage

The Input / Output Controller is to be used for monitoring the functional capability and the yield of the solar circuit of solar thermal systems in compliance with the technical data specified in this manual.

Improper use excludes all liability claims

Instructions

Attention should be paid to

- valid local regulations
- the statutory provisions for prevention of industrial accidents,
- the statutory provisions for environmental protection,
- the Health and Safety at Work Act 1974
- Part P of the Building Regulations 2005
- BS7671 Requirements for electrical installations and relevant safety regulations of DIN, EN, DVGW, TRGI, TRF and VDE.

These instructions are exclusively addressed to authorised skilled personnel.

- Only qualified electricians should carry out electrical works.
- Initial installation must be effected by qualified personnel named by the manufacturer

Subject to technical change. Errors excepted.

Table of contents

CE-Declaration of conformity

The product complies with the relevant directives and is therefore labelled with the CE mark. The Declaration of Conformity is available upon request, please contact RESOL.

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Annex II: INGA-IBS IOC-Web-Server

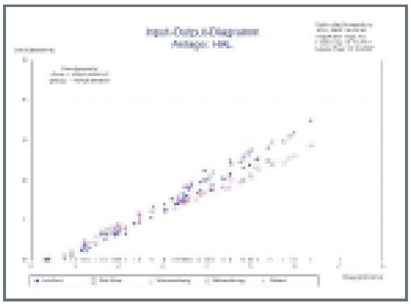
Web-based yield control of thermal solar heating systems (Web-IOC)

Introduction:

The quality and the reliable function of thermal solar heating systems are the most important criteria for lining up investment decisions. It is indeed well known that redundant and trouble-free operation of solar heating systems is not self-evident, mostly because of the fact that even major malfunctions in the solar part - the collector loop - may remain hidden because of automatic additional heat delivery by an auxiliary heater. Therefore there is a substantial need at inexpensive however sufficiently exact yield control systems for solar heating systems. Conditions to the function control are simulation procedures for expected yields as well as a monitoring technology for durable yield examination.

The procedure:

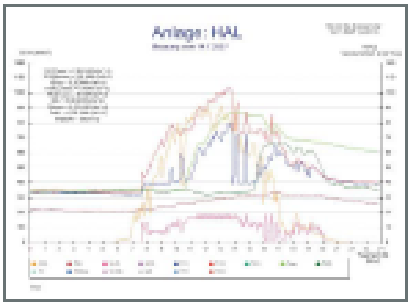
The functional monitoring and yield control of thermal solar heating systems are based on the patented Input-Output-Controller-Technology of the institute for solar energy research Hameln/Emmerthal (ISFH). It is characterised by continuous monitoring, minimum auxiliary costs as well as transparency, sufficient accuracy and practice fitness.



It is based on the independent accomplished comparison of expected and actual values of the daily collector circuit yield and allows the automatic determination of the expected collector circuit yield on the basis of standardized collector characteristic values and the measured values of the solar heating system.

The system:

The overall system represents a web-based, independently working "measured value admission and evaluation unit", which can determine the expected value of the daily solar yield and compare it to the actual yield. It unites energy data acquisition, energy data analysis and energy data simulation, and shows without manual intervention whether the system runs in the expected efficiency range or whether significant deviations of the measured yield from the theoretical yield are present.



Several locally separated solar heating systems can be supervised by the purposeful creation of a web-based solution. On site no PC hardware is necessary – only a data logger for the collection of the sensor data needs to be installed. The data from the data logger is read by the central server by modem; alternatively the data logger sends the data to the server independently.

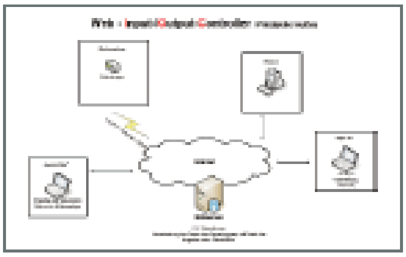
The results can be accessed via internet; special software is not needed. By means of user name and password the assigned solar heating systems and the evaluated data can be accessed. Results are displayed as numbers as well as diagrams. Also disturbing-messages and warnings from the installation or from the analysis of the measured values are displayed. These can also be passed on directly (by email, SMS, fax etc.)

For more exact analyses by special software the raw data can be downloaded, alternatively experts can be contacted.

Operational areas:

The Web IOC serves the durable monitoring of thermal solar heating systems. Since the system does not have to fall back to a data pool of several days in order to obtain results and already works with the data of only one day, it can be used for example to proof the function of new solar heating systems.

Due to the standardized field technology (sensor technology, data logger, modem) a use is conceivable even for further purposes.



Advantages of a web-based system:

- More economic as there is no additional hardware needed
- System updates will be accomplished centrally, no expensive and complex updates and upgrades
- No administration expenditure for additional computers
- Results can be accessed from everywhere
- Alarming functions are available without large expenditure
- Experts are able to access raw data and result data quickly from everywhere to make an analysis
- Data from existing systems can be taken over

INGA mbH
Wehler Weg 14 Tel: +49 5151 9451-0 E-Mail: ioc@inga-hameln.de
D-31785 Hameln Fax: +49 5151 21202 Web: www.inga-hameln.de

Annex III: Bosch Thermotechnik GmbH Control Unit

Innovation

Funktionskontrolle und Ertragsbestimmung von Solaranlagen

- Fortschrittliche Fehlererkennung und –behandlung von einfachen bis komplexen thermischen Solaranlagen durch Systemregler der Bosch Thermotechnik GmbH. -

Bosch Thermotechnik GmbH

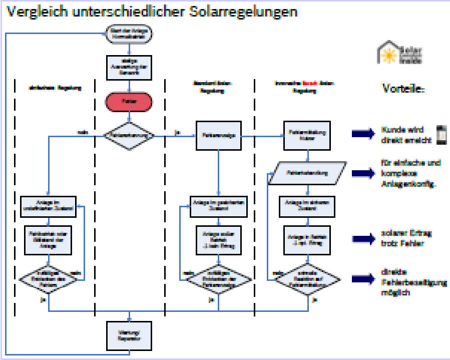
Einleitung

Die einwandfreie Funktion einer Solaranlage hängt von sehr vielen Faktoren ab. Kann also von einer durchgehend fehlerfreien Inbetriebnahme bzw. Betrieb von solarthermischen Anlagen ausgegangen werden?
Eine Vielzahl möglicher Fehler sind in den Fehlerlisten der VDI 2169 und in dem Informationsblatt Nr. 17 des BDH beschrieben. Wichtige Beispiele sind Luft im System, Fühlerbruch oder Pumpendefekt. Diese Fehler führen in der Regel zu einem Stillstand der Anlage und damit zum Ertragsausfall. Fehler treten auch bei der Installation auf. Sie führen nicht zwangsläufig zum Stillstand, können jedoch deutliche Ertragseinbußen bewirken. Diese Installationsfehler sind vor allem bei komplexen Anlagen zu finden.

Systemregler der BOSCH Thermotechnik GmbH nutzen innovative Mechanismen um den Ertragsverlust für den Nutzer zu minimieren.

Ablaufdiagramm

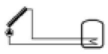
Vergleich unterschiedlicher Solarregelungen



Fehlererkennung

Eine stetige Auswertung der gegebenen Sensorik erlaubt die Funktionskontrolle. Durch intelligente Verknüpfung der Informationen wird eine umfangreiche Fehlererkennung ermöglicht. Dazu gehören die typischen Fehler für **klassische** Solaranlagen:

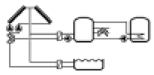
- Temperaturfühler
  - falscher Fühlertyp bzw. Fühler vertauscht
  - Fühler falsch positioniert
  - Fühler defekt



- kein Umlauf
  - Luft im System
  - blockierte Pumpe

aber auch die Erweiterung für **komplexe** Anlagen:

- Mehrspeichersystem
  - vertauschte Speicherfühler
  - falsche Umschaltlogik

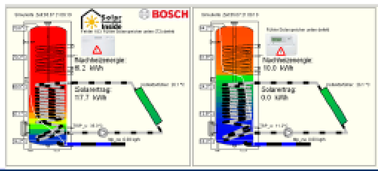


- vertauschte Kollektorfühler bei zwei Kollektorfeldern
- Fühlerkontrolle am externen Wärmeübertrager

Fehlerbehandlung

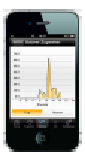
Wichtige Ergänzung und logischer Schritt nach der Fehlererkennung ist die Fehlerbehandlung. Der Systemregler der BOSCH Thermotechnik GmbH kompensiert den Fehler soweit wie möglich und nutzt im Fehlerfall alternative Regelstrategien.

- Dies bedeutet für den Nutzer erhebliche Vorteile:
  - Weiterbetrieb der Anlage
  - Solarer Ertrag trotz Fehler
  - Übermittlung von Systeminformationen auf Smartphones
  - Zügige Fehlerbeseitigung möglich durch aktive Fehlermitteilung



Ertragsbewertung

- Ertragsermittlung gibt dem Kunden die Möglichkeit (weitere) Anlagenfehler zu erkennen
- Reglereinheiten der BOSCH Thermotechnik GmbH bringen diese Eigenschaft bereits mit
- "Kennenlernzeit" zur Charakterisierung und Analyse der Anlage
- keine zusätzlichen Messeinrichtungen notwendig
- Ertragsabschätzung erhöht Transparenz der Anlage und macht sie bewertbar
- Darstellung der Ertragswerte auch auf Smartphones möglich



Fazit

- Einmaliger Funktionsumfang für Solarregler
- Erhöhte Betriebssicherheit vor allem bei komplexen Anlagen
- Erfüllung der in der VDI-Richtlinie 2169 benannten Punkte der "Automatischen Funktionskontrolle" und "Ertragsbewertung"
- Hohe Anlagentransparenz durch aktive Fehlerübermittlung und Darstellung von Anlageninformationen in stündlicher und monatlicher Auflösung
- zügige Fehlerbehebung realisierbar

09.-11.05.2012 | TT-STT

BOSCH