

Quality assurance with the ISFH-Input/Output-Procedure 6-year-experience with 14 solar thermal systems

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1. Introduction

The operators of standard solar thermal systems usually don't recognise failures affecting the solar yield, because an auxiliary heater supplies the consumers with warm water even in the case of failures. In order to assure the operator that the solar system is working properly over its lifetime, a procedure for controlling the solar heat has been developed at ISFH since Dec. 1999 and tested in 14 different solar thermal systems. Our motivation is to help removing the reluctance of investors of medium solar thermal systems by increasing the confidence in solar thermal energy.

The so called Input/Output-Procedure is controlling the solar heat by an automatic comparison of measured and expected collector yields on a daily basis. The expected collector yield is calculated with a simplified simulation model.

Because the Input/Output-Algorithm is very compact, it can be integrated into standard control units, so that low-cost-devices are realisable. Prototypes of I/O-Controllers (IOC) with an implemented algorithm have been installed in 14 different solar systems. The simulation model was validated with measured data and a lot of failures in 11 solar thermal systems could be detected in the past six years.

In a sensitivity analysis that takes into account both the uncertainties of the parameters as well of those of the measurements, the over-all uncertainty of the procedure has been determined to about 7 %.

2. The ISFH-Input/Output-Procedure

2.1 General specifications

For the daily comparison of measured and expected collector yields, the I/O-Controller has to measure the heat output as well as the input quantities of the simulation model for the calculation of the expected out-put.

Fig. 1: Schematic diagram of the integration of an Input/ Output-Controller and associated sensors into a solar system with buffer storage tank and direct discharging.

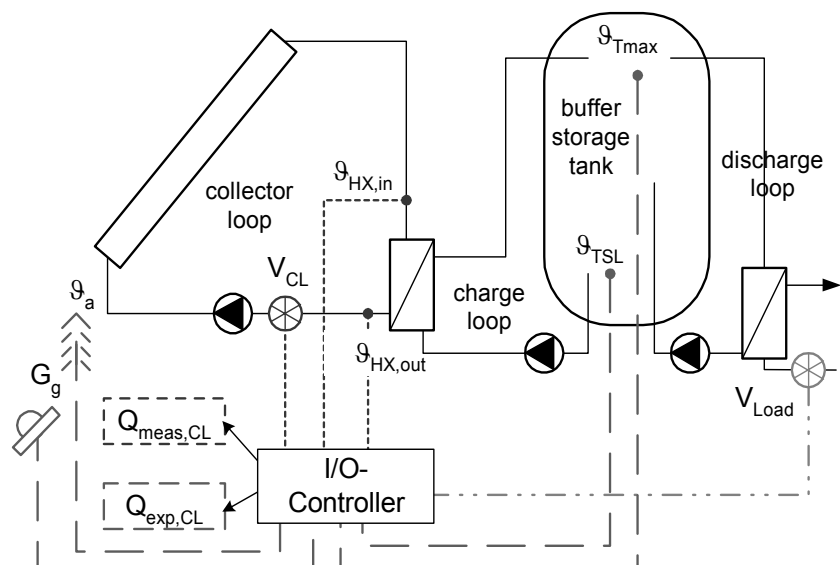


Figure 1 shows the sensors which are typically required for the Input/Output-Procedure. Optional sensors may be installed for more information or in order to facilitate trouble-shooting in case of a failure.

For the measurement of the yield of the collector loop $Q_{\text{meas,CL}}$ the volume flow rate V_{CL} and the temperature difference between inlet and outlet of the heat exchanger ($\vartheta_{\text{HX,in}} - \vartheta_{\text{HX,out}}$) are required. The expected yield $Q_{\text{exp,CL}}$ is simulated with measured data of irradiance G_g , ambient air temperature ϑ_a , typical solar load temperature ϑ_{TSL} and the high-limit cut-off temperature ϑ_{Tmax} . 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, tilt, collector area).

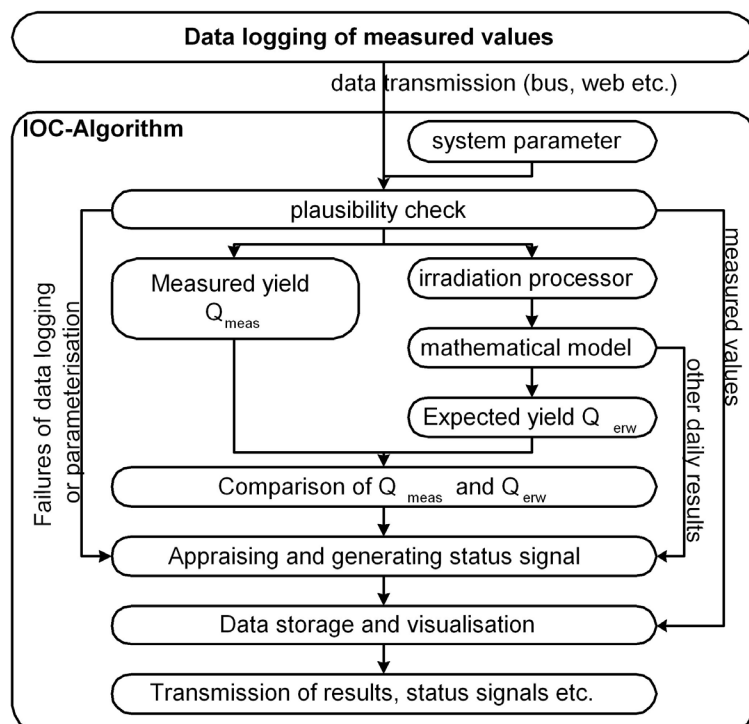
The ϑ_{TSL} describes the temperature of the heat sink of the collector loop, which can be a (buffer) storage tank, a return pipe of a district heating system etc. The main advantage of using the ϑ_{TSL} is that the same mathematical model can be taken for the collector loop of all kinds of systems.

2.2 The Input/Output-Algorithm

The structure of the IOC-Algorithm is shown in figure 2. At first, the logged measured data as well as the parameters are checked for plausibility within the IOC-Algorithm. Then, on the one hand, the measured yield is calculated and, on the other hand, the expected yield is simulated by solving a mathematical model of the collector loop.

The irradiation processor is dividing the global irradiance into diffuse and direct radiation and calculates its incidence angle.

Fig. 2: Structure of the Input/Output-Algorithm that can be integrated into standard control-units or servers.



At the end of the day, the deviation between the two values Q_{meas} and Q_{exp} is determined automatically. Together with additional information of the plausibility check and other results of the simulation, the generated status signal specifies as accurate as possible the cause of the failure. In order to facilitate trouble-shooting, measured data as well as simulation results are stored.

The measured and expected daily outputs of the collector loop can be plotted vs. the daily irradiation (input) in an Input/Output-Diagram (q. v. Fig. 3). Solar domestic hot water systems show a well-known linear relationship, but also solar systems for space heating that do not show such a linear population can be controlled with an Input/Output-Controller, because of the dynamic simulation of the expected output. Failures in the collector loop can be seen easily in an Input/Output-Diagram, because the measured values strongly deviate from the expected values.

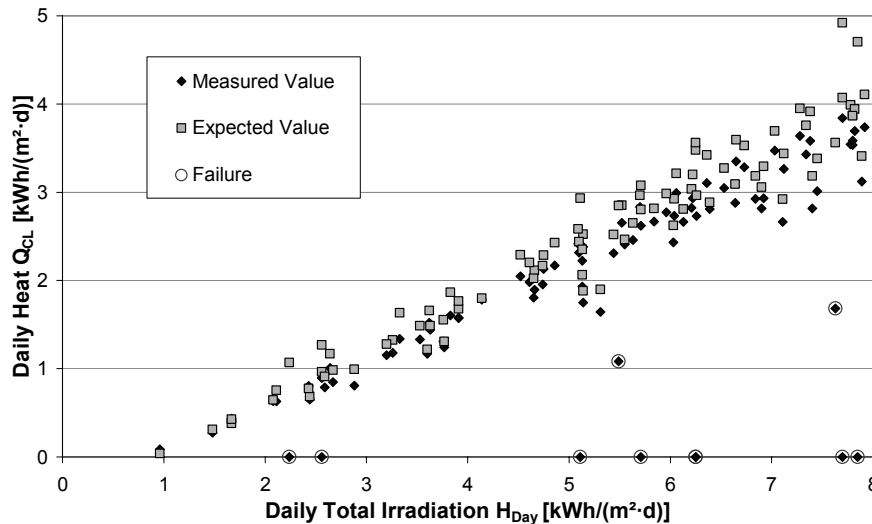


Fig. 3: Input/ Output-Diagram of an attended solar system of a hospital in Solingen (192 m²) from 2003. The failure occurred in the collector loop. The measured yields of the collector loop strongly deviate from the expected yields (encircled measured values).

The volume flow rate of the load V_{Load} (warm water consumption) and the storage temperature at the relevant position for the high-limit cut-off ϑ_{Tmax} (q. v. Fig 1) are important information for the algorithm to distinguish a failure in the discharge loop from the effects of lacking heat demand, so that discharging failures can be detected. In case of low heat demand, e. g. in holidays or in summer periods for solar combi-systems, no significant difference between measured and expected values results. This is important to avoid false signals that confuse the operator, because this is a normal state of solar systems.

2.3 Mathematical model

One goal for the development of the mathematical model for the collector loop was that it should be applicable for the implementation into standard control units. For that reason the heat demand V_{Load} is not an input for the model as it is for typical simulation programs. Instead the input quantity for the model is the typical solar load temperature ϑ_{TSL} . By using the ϑ_{TSL} the following advantages were achieved:

- Applicability for various solar system-types without adaptation of the algorithm
- Differential equation is solvable analytically, accurate enough and can be integrated into standard control units

→ Possibility for implementation into small inexpensive I/O-Controllers!

2.4 Sensitivity analysis

For the interpretation of the deviation between measured and expected collector yield (Q_{meas} and Q_{exp}) the uncertainty of the Input/Output-Procedure has to be known. The uncertainty of the Input/Output-Procedure depends on the uncertainties of parameters, measured values and simplifications of the simulation.

Comparisons of validation studies against measured data using Input/Output- and TRNSYS-results showed similar accuracy patterns for both simulation methods.

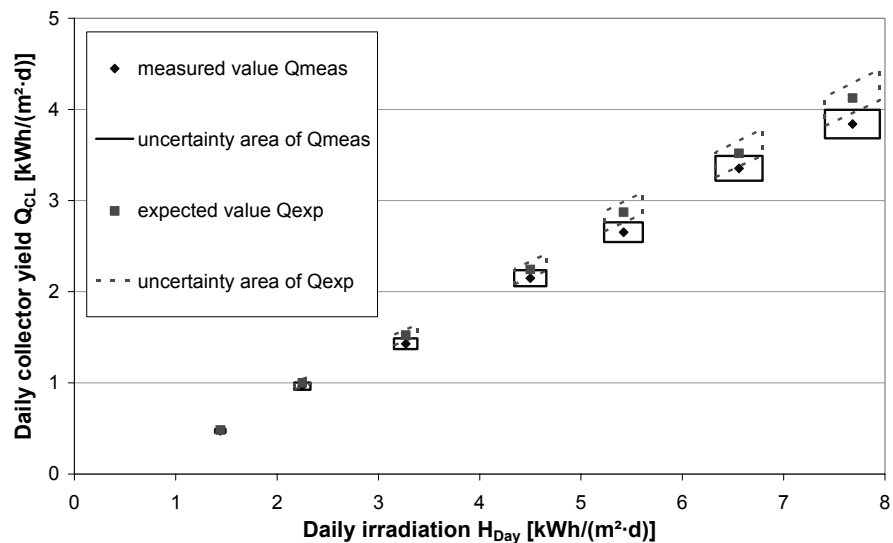
The joint influence of the uncertainties of parameters and measurement on the uncertainty of the I/O-Procedure was analysed in a sensitivity analysis. This is done in three steps:

- At first, the uncertainties of the parameters as well as the measured values have to be assumed conservatively.

- Next, the original values of the parameters and the measured data were modified with their standard uncertainty in order to calculate their effect on the collector output. This was done with data of one year of a typical solar system.
- At last, all the individual uncertainties have to be added as root sum of squares because they do not occur in the same direction.

The mean uncertainty of the expected yield of the collector loop results to 5.2 %, while the uncertainty of the measured yield of the collector loop is approx. 4 % (q. v. Figure 4). Taking both effects into account, the standard uncertainty of the Input/Output-Procedure follows to about 7 %. Our suggestion is to fix a triple standard uncertainty as tolerance limit. Thus, a fault can be detected with a probability of 99 % if a difference between measured and simulated yield of 20 % is exceeded. Because of increasing uncertainties of the simulation for low irradiation values, the tolerance is modified to an absolute value of 0.3 kWh/(m²·d) for expected yields below 1.5 kWh/(m²·d).

Fig. 4: Schematic diagram of the uncertainty areas of Q_{meas} and Q_{exp} as well as the suggested tolerance area.



Conclusions

- The ISFH-Input/Output-Procedure provides automatic in situ controlling of the measured collector loop yield by comparing it with a simulated value.
- The dynamic simulation algorithm to calculate the expected yield can be integrated into standard control units because the mathematical model is simple and analytically solvable. This enables low-cost Input/Output-Controllers.
- The mathematical model has been validated against measured data of 19 different solar systems. The average deviation is under 10 % which exceeded our expectations. The model is applicable for various solar systems without adaptation of the algorithm.
- The uncertainty of the I/O-Procedure concerning the uncertainties of parameters and measured data is about 7 %. If the limit of tolerance between measured and simulated yield of e. g. 20 % is exceeded a fault is existent with a probability of 99 %.
- The first licence is given to RESOL® that will offer I/O-Controllers on the Intersolar2007. Other interested parties are welcome.

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