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ScienceDirect

Solar Energy 85 (2011) 1430–1439

SOLAR ENERGY

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Review of long-term fault detection approaches in solar thermal systems

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Received 15 September 2009; received in revised form 4 January 2011; accepted 28 March 2011
Available online 2 May 2011

Communicated by: Associate Editor C. Estrada-Gasca

Abstract

This paper presents an overview, assessment and comparison of automated fault detection methods that check if solar heating systems are functioning correctly. Fault detection in solar thermal systems is important to minimize the time when the system is not functioning well, thereby ensuring an optimal energy (and economic) yield.

During the past decades many systems have been monitored, mainly for scientific or demonstration projects by logging measurement data which was subsequently analysed by an expert. Automation of fault detection is necessary to reduce costs and minimize experts' time needed for analysis of a system. An overview of existing fault detection approaches is given; these are evaluated and compared with a multi-criteria analysis.

The only commercially available automated method, the Input–Output Controller, detects faults causing more than 20% energy loss in the solar loop. The function control approach is cheap without a heat meter, and only relies on few sensors to check how several components in the solar loop are functioning with algorithms. The approach developed at Kassel University checks how well a solar plant is functioning both with plausibility checks and with energy balances based on simulations. This method includes a larger part of the solar heating system and therefore requires more measurement equipment.

Further research and application of several fault detection methods should improve the effectiveness and costs of these methods.

Keywords: Solar heating systems; Monitoring; Fault detection

1. Introduction

Solar thermal energy is expected to make a major contribution to the sustainable supply of low temperature heat in the future. The reliability of solar thermal systems (STS) and components is important in order to obtain an optimum energy production. During the approximately 25 year life span of STS, a fault detection system could result in a quick response and prompt reparation of an occurring malfunction and can offer the following benefits:

- *Minimisation of energy and economic losses*, due to quicker repair of the fault. Normally faults are not noticed directly, since hot water demand and irradiation are variable and since the auxiliary heating continues to supply warm water.
- *Remote supervision*, solar thermal systems are decentralised and the owners are usually not experts, therefore remote supervision is useful.
- *Reduction of repair costs*, due to more accurate knowledge of the fault and when it occurred.
- *Improved reputation*, monitoring can prove whether a system is functioning properly and will on the long term lead to better functioning systems. A threat for the solar thermal market is 'discredit due to bad previous examples' (Tsoutsos, 2002).

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doi:10.1016/j.solener.2011.03.025

Nomenclature

F'	collector efficiency factor
H_{Day}	daily irradiation, kWh
H_{insuf}	part of H_{Day} that is insufficient to generate an energy yield, kWh
$K_{\theta,eff}$	effective angle of incidence correction, averaged over the operation time
T	temperature, °C
Q_{cc}	daily heat gain of the collector loop, kWh
$Q_{v,Kap}$	capacitive losses of the collector loop, kWh
$Q_{v,th}$	thermal losses of the whole collector loop, kWh
U	overall heat loss coefficient, W/K
η_0	zero-loss collector efficiency
σ	standard deviation

- *Support for further development of solar thermal technology*, components and systems can be improved based on detailed information on the functioning of certain components or system hydraulics.

During the last decades several monitoring and fault detection approaches have been developed. To date, however, fault detection systems are more frequently applied to demonstration or scientific oriented projects than to commercially operated systems. Furthermore, in many cases, a classical approach is used in which the measured data from temperature, heat and flow sensors are automatically logged, but these data are not automatically analysed for faults. A detailed analysis by an expert is costly and not generally applicable for all commercial systems, because of a lack of experts. Therefore, several research groups have started developing automated monitoring approaches. Challenges during the method development are, for example, the large diversity in hydraulics of STS, preventing false alarms and a low end cost for fault detection. This paper intends to bridge the knowledge gap about existing fault detection approaches. An overview of these approaches is given and the methods are compared and evaluated using a multi-criteria analysis. In Section 2, an overview of weaknesses and faults that can occur during the operation of solar thermal systems is given. The fault detection methods are described in Section 3. Both, automated and manual fault detection methods are included as well as methods for all sizes of STS. The multi-criteria analysis and the application for fault detection methods are described in Section 4. The results of the evaluation are presented in Section 5.

2. Malfunctions during the operation of solar thermal systems

The type of faults and their frequency of occurrence in STS were studied by several German and Austrian groups. Because of the large diversity in system hydraulics, locations and installation years, these experiences are not generally valid for all system types or situations.

The German 'Center for Solar Technology' (ZfS) analysed the functioning of 98 systems built between 1978 and 1983 in the Future Invest Programme (ZIP) in early 2000 and of 60 systems built between 1995 and 2005 within the Solarthermie 2000 (ST-2000) Program in 2008 (Peuser et al., 2002, 2008). The results are presented in Fig. 1. The ZIP systems were analysed based on the outcome of detailed questionnaires. Many defects were related to the infancy of the technology and almost or completely disappeared for the systems built in ST-2000, especially malfunctions related to the collector.

Nevertheless, in the ST-2000 Program still many system faults were found, even though the operation time of the systems was much lower. Notable is the high defect rate of the pumps and heat exchangers. Also problems with control, ranging from false settings via falsely placed temperature sensors to unsuitable controllers are noteworthy. 20% of the controllers had to be replaced.

In the Austrian Optisol project the performance of 10 large solar thermal systems during start up and a two month optimization phase were analysed between 2004 and 2006 (Fink et al., 2006). Many weaknesses were identified, for example, the integration or operation of the auxiliary heating system, an unnecessary large auxiliary heating volume in storage, too high return temperatures of the net and a suboptimal speed control of pumps.

On the one hand, the quality of components and systems can be enhanced by introducing a quality label like the SOLAR KEYMARK for collectors and small systems (SOLAR KEYMARK, 2008). On the other hand, a fault detection system is necessary to ensure a quick detection and reparation of an occurring malfunction.

3. Overview of fault detection methods

3.1. Fault detection with manual analysis (MM)

The standard approach for fault detection in solar thermal systems consists of automatic data logging of measurements of several temperature and flow sensors and sometimes irradiance measurements, followed by a detailed manual fault analysis by an expert. There is a large variation in the amount and quality of measurement equipment installed and in how the gathered data is analysed. If the quality of the measurement data is good, temperature