D-CAT: In-Situ Test for Large Solar Thermal Collector Arrays Based on Grey-Box Modeling

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Content

Large-scale solar thermal systems are a cost-effective way to provide renewable heat [1]. The market has recently experienced considerable growth, hence there is a need to precisely estimate and monitor these systems, based on field measurements of collector arrays. This contribution presents the *Dynamic Collector Array Test (D-CAT)*, an in-situ test method for detailed quality assessment of large collector arrays under fully dynamic operating conditions. The method has been developed in the Austrian funded research project *MeQuSo* [2]. The test procedure has been applied to the plant FHW (Fernheizwerk, see Fig. 1) in Graz, giving detailed performance results for five large flat-plate collectors of different European manufacturers. The general approach of D-CAT includes the development and validation of a dynamic collector array model, improved radiation modelling, optimal data selection for the estimation and grey-box estimation of the model parameters. The D-CAT method can run in parallel to the normal system operation and does not require adapting the system control.

Methods

Model

The context of this contribution is the in-situ testing of large solar thermal collector arrays, a question that has been answered satisfactorily for laboratory tests of single collectors in the ISO 9806 standard [3]. The D-CAT method extends this well-known single-collector test method in two ways:

1) It is adapted to the boundary conditions of collector arrays. This mainly affects dynamic system behavior and solar radiation; both are addressed by suitable physical models.
2) It runs in-situ (not in a laboratory) and does not interfere with the control. The wide range of model validity allows to use almost all operating data in the estimation process.

The model parameters need to have a physical interpretation – an important aspect that goes in line with the goals of the approach in the ISO standard [3], for single collector tests. The presented method is based on a dynamic state-space model that is as close as possible to the physical approach used in the ISO standard. The model equations in PDE form:

$$(mc)_m \frac{\partial T_m}{\partial t} = (\tau\alpha)(K_b(\theta)G_b + K_d G_d) - a_1(T_m - T_a) - a_2(T_m - T_a)^2 - D\alpha(T_m - T_f)$$

$$(mc)_f \frac{\partial T_f}{\partial t} = D\alpha\left(T_m - T_f\right) - \dot{C}_f \frac{\partial T_f}{\partial x}$$

This model is the result of a variety of grey-box models that have been tested and validated against the measurement data coming from the FHW plant. This model describes the collector array behavior by means of 9 parameters. These parameters are lumped for the whole collector array, characterizing the “typical” collector that best represents the array operation.

Data Handling and Parameter Estimation

Measuring data have been acquired within the MeQuSo project; the data refer to 5 collector arrays of the FHW plant in Graz. The measured channels include input and output temperatures and volume flow of each array, beam and diffuse radiation, and ambient conditions. All channels have been acquired in a 1-second sampling rate, averaged to 10 seconds during post-processing.

All data intervals with a length of at least 1.5 hours of unshaded operation are included in the analysis, yielding around 500 intervals per year. In an optimal data selection process based on the data’s Fisher information with respect to the model, a set of “D-optimal” intervals is selected. This approach ensures

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high quality parameter estimates, good generalization to non-observed operating conditions and improved optimization time. All data processing is done in a fully automated way, including raw data treatment and pre-processing, optimal data selection, to final results of the model estimation process.

Results

The devised D-CAT test method can be used for performance monitoring and detailed assessment of large solar thermal systems. The estimated model parameters, obtained as a multivariate random variable, reflect the current state of a tested collector array. The parameters have a straightforward physical interpretation: In particular, the D-CAT approach enables one to separate weather influence from the behavior of the collector array, seen as a technical component. This yields a clear and concise answer to discussions among involved stakeholders, e.g. plant operator and collector manufacturer.

Together with the employed physical model, various interesting applications are possible:

- One application is to produce short-term predictions, e.g. for model-predictive control.
- Another application are long-term system simulations delivering KPIs (e.g. energy yield plus confidence intervals) to be used by plant operators for making informed decisions.
- Predictive maintenance based on the temporal evolution of system parameters over time.

The D-CAT method has been applied to 3 years of field measurement data, using an implementation in a software project that runs the test in a fully automatic way. The test method can also be triggered on demand, based on a simple and fast static system analysis.

The long paper version for the symposium can include more details and figures about the results, the theoretical approach and used methods. Overall, our method is a contribution to the integration and operation of large collector arrays as stand-alone systems or within energy systems.

Figure 1: Aerial view of the FHW collector arrays. Source: Picfly.at Thomas Eberhard

References

[1] ESTIF, 2015. “Solar Thermal Markets in Europe. Trends and Market Statistics 2014.” ESTIF, Brussels.
[2] Tschopp, Daniel, et al. "In-situ Testing of Large Collector Arrays–Challenges and Methodological Framework." (2017).
[3] ISO 9806:2017(E): Solar energy — Solar thermal collectors — Test methods.