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Artificial neural networks for the performance prediction of large solar systems

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ABSTRACT

In this paper, artificial neural networks (ANNs) are used for the performance prediction of large solar systems. The ANN method is used to predict the expected daily energy output for typical operating conditions, as well as the temperature level the storage tank can reach by the end of the daily operation cycle. These are considered as the most important parameters for the user. Experimental measurements from almost one year (226 days) have been used to investigate the ability of ANN to model the energy behavior of a typical large solar system. From the results, it can be concluded that the ANN effectively predicts the daily energy performance of the system; the statistical R^2-value obtained for the training and validation data sets was better than 0.95 and 0.96 for the two performance parameters respectively. The data used in the validation were completely unknown to the ANN, which proves the ability of the ANN to give good predictions on completely unknown data. The results obtained from the method were also compared to the input–output model predictions with good accuracy whereas multiple linear regression could not give as accurate results. Additionally, the network was used with various combinations of input parameters and gave results of the same order of magnitude as the suggested method, which prove the robustness of the method. The advantages of the proposed approach include the simplicity in the implementation, even when the characteristics of the system components are not known, as well as the potential to improve the capability of the ANN to predict the performance of the solar system, through the continuous addition of new data collected during the operation of the system.
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1. Introduction

The development of large capacity installations for the exploitation of solar thermal energy can be characterized as critical for the broadening of solar thermal energy applications [1]. Such an expansion though, seems to come up against the suspicion of the potential users regarding the expected energy benefit, and consequently the reciprocity of the required investment. From this point of view, the realistic evaluation of the energy performance of large solar thermal systems (LSTS) constitutes a critical parameter, not only for the candidate investor, but also for any type of supporting actions provided by the state.

In the case of small, standardized, factory-made domestic systems, the demand for reliable information regarding the expected energy output is satisfied by national or regional certification systems, the implementation of which is based on the existing testing and requirements standards (EN12976-1, Solar Keymark). A LSTS though is one of a kind, designed in accordance with the satisfaction of the particular requirements for a specific application. The discussion thus, concerns custom-made, non-standardized systems, where the only available information for the energy performance comes out from the initial long-term performance prediction made in the study phase. Often, this information is characterized by significant uncertainties, which can be attributed to the simplified working hypotheses of the calculation methods, the lack of information regarding the characteristics of the subsystems employed (collectors, storage tank, controller, hydraulics), or even more to the insufficient knowledge of the actual load profile [2,3].

Even though each LSTS is unique, the demand for reliable information regarding its actual energy performance is of critical importance, mainly for the following reasons:

- The comparison of performance prediction, made in the study phase, with the actual performance of the system, will assist the

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user to shape a realistic view for the reciprocity of the investment required, and, eventually, to redesign some elements of the energy system (e.g. changing of the capacity of the auxiliary sources).

- The analysis of potential significant deviations between the predictions and the actual performance, may lead to the detection of failures related to the implementation phase, and to the elaboration of corrective actions.
- The continuous comparison of actual energy performance to the predicted one, or the one which had been initially verified, can be proved to be valuable for the on time detection and correction of potential malfunctions which have appeared in due course. Such a comparison could be implemented on an automated basis by the control system, which would also undertake the activation of the proper alarms in case of a problem.

Moreover, the need for extending the certification of solar thermal systems on large capacity custom-made systems has turned the interest on methodological approaches which allow the reliable assessment of the expected energy benefit [4,5]. Within this context, the discussion of the methodologies suitable for the verification of energy performance of LSTS has been intensified in recent years [6,7].

Thus, the comparison between expected and actual performance presupposes the existence of a simulation tool, which would allow the reliable estimation of the expected energy benefit of a LSTS, as this system has been finally implemented. Such a tool can belong in one of the following two main categories:

- Models which allow the dynamic simulation of the system behavior on the basis of information related to its structure and the characteristics of the individual subcomponents, e.g. TRNSYS [2,3]. The quality of the predictions by such models is a function of the reliability of the available information, noting the usual significant deviations between the final actual configuration of a LSTS and the working hypotheses of the initial study. These concern mainly the weather data used in the simulation, usually in the form of a Typical Meteorological Year (TMY), and the load profile assumed, which strongly depends on the habits of the user/s and the type of application (hotel, industry, etc.). An additional difficulty is related to the requirement for specialized knowledge and adequate experience by the personnel responsible for the operation of the specific software.
- Models, which treat the LSTS as a black box, and their application, can be performed on two distinct phases. In the first phase, i.e., training, experimental measurements taken through operation of the system are exploited, in order to shape an adequate picture for the behavior of the system (mapping). The calculation procedure uses experimental information in order to elaborate a kind of energy identity for the system, usually under the form of coefficients of one or more characteristic equations. Advantages of this kind of models include the relatively simple use and the realistic assessment of the performance of the system as it has been finally configured. As a disadvantage, one may consider the inability to perform simulation for configurations or conditions of use significantly different from the ones used during the training phase [6].

Another factor, which influences the quality of results of the discussed models, is the operating conditions assumed. Given the stochastic variation of meteorological conditions and their large influence on the energy behavior of the solar system, in order the discussed comparison between expected and actual performance to be realistic, this comparison has to be performed for certain reference conditions, the same as the ones used during the planning phase. Actually, this concerns not only the meteorological conditions, for which the Typical Meteorological Year is in most cases used, but also the load profile, which has to be as close as possible to the conditions of use.

The proposed work aims to present a new approach, which belongs on the second category of models, and it is based on the availability of short term, relatively simple measurements, as well as on the exploitation of Artificial Neural Network (ANN) method. The proposed approach is quite simple to use, and can be easily implemented for the verification of the predictions of the initial study, as well as for the real-time inspection for potential malfunctions [8].

The structure of the paper is as follows: In Section 2 the concept of Artificial Neural Networks is presented and their potential for the simulation of energy processes is discussed. In Section 3 the experimental set up is discussed, as well as the protocol of the elaborated measurements, while in Section 4 the ANN performance is analysed and the potential of implementing ANN in actual LSTS applications is discussed, and finally, in Section 5 the conclusions of the overall investigation are presented.

2. ANN modeling of energy systems

Although the concept of artificial neural network (ANN) analysis has been discovered nearly 60 years ago, it is only in the last 30 years that application software has been developed to handle practical problems. ANNs are good for some tasks while lacking in some others. Specifically, they are good for tasks involving incomplete data sets, fuzzy or incomplete information, and for highly complex and ill-defined problems, where humans usually decide on an intuitive basis [9].

ANNs have been applied successfully in various fields of mathematics, engineering, medicine, economics, meteorology, psychology, neurology, and many others. Some of the most important ones are; pattern, sound and speech recognition, analysis of medical signatures, identification of military targets and of explosives in passenger suitcases. They have also been used in weather and market trends forecasting, prediction of mineral exploration sites, electrical and thermal load prediction, adaptive and robotic control and many others [10].

Artificial neural networks are systems of weight vectors, whose component values are established through various machine-learning algorithms, which take a linear set of pattern inputs and produce a numerical pattern representing the actual output. ANNs mimic somewhat the learning process of the human brain. Instead of complex rules and mathematical routines, ANNs are able to learn key information patterns within a multi-information domain. In addition, inherently noisy data does not seem to present a problem, as ANNs are tolerant in noise variations [11].

Artificial neural networks differ from the traditional modeling approaches in that they are trained to learn solutions rather than being programmed to model a specific problem in the normal way.

Table 1
Technical specifications of the system employed.

Parameter	Value	Units
Collector aperture area, A_C	2.59	m^2
Maximum collector efficiency, n_o	0.732	[–]
Overall collector heat loss coefficient, U_C	4.455	$Wm^{-2}\ K^{-1}$
Effective thermal capacity of collector, $(MC)_C$	29	$kJ^{-}K^{-1}$
Water content in collector, W_W	5.8	kg
Number of collectors in the field, N_C	48	[–]
Heat-exchanger overall heat transfer coefficient, $(UA)_{ex}$	13,300	$W\ K^{-1}$
Storage tank volume, V_S	32,000	l
Overall storage tank heat loss coefficient, $(AU)_S$	150	$W\ K^{-1}$

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