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Review

Neuro-fuzzy dynamic model with Kalman filter to forecast irradiance and temperature for solar energy systems

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Abstract

This paper introduces a dynamic forecasting of irradiance and ambient temperature. The medium term forecasting (MTF) gives a daily meteorological behaviour. It consists of a neuro-fuzzy estimator based on meteorological parameters' behaviours during the days before, and on time distribution models. As for the short term forecasting (STF), it estimates, for a 5 min time step ahead, the meteorological parameters evolution. It is ensured by the Auto-Regressive Moving Average (ARMA) model of the MTF associated to a Kalman filter. STF uses instantaneous measured data, delivered by a data acquisition system, so as to accomplish the forecast. Herein we describe our method and we present forecasting results. Validation is based on measurements taken at the Energy and Thermal Research Centre (CRTEn) in the north of Tunisia. Since our work delivers accurate meteorological parameters forecasting, the obtained results can be easily adapted to forecast any solar conversion system output.

Keywords: Meteorological forecasting; Modelling; Neuro-fuzzy; ARMA; Kalman filter

Contents

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1. Introduction

Accurate forecasting of irradiance and ambient temperature behaviours during daylight is required in most solar energy applications, particularly in design methods, in system characterization and in decision making for energy management. Different models were introduced in literature so as to forecast irradiance. Evaluations, with respect to measured data uncertainty, of the accuracy of many model approaches where no measurements are available were proposed [1]. More complex modelling methods gave empirical models or spatial and temporal variations [2,3]. Measurements based models were also proposed using either METEOSAT images [4] or meteorological station measurements [5]. Recent methods for forecasting daily total irradiance such as adaptive wavelet network [6] and fuzzy logic [7] were introduced. Since these researches aimed to offer tools for solar plants sizing, they estimated yearly, monthly and daily irradiance relying on long term data which is not always available for all sites. Other researches used weather forecasts provided via e-mail by meteorological institutes [8,9] in order to build solar plants control. Even if forecasted meteorological parameters are truthful, the method remains unsuitable for all solar applications as it depends on Internet connection state.

Although produced results are significant, they present many insufficiencies. First, most researches were interested in irradiance modelling without considering ambient temperature. Second, they did not estimate correctly and easily in short term the quantity of solar energy collected which prevented real time plant energy forecast and management. In addition, since meteorological parameters are stochastic signals, the introduced methods could not provide accurate forecasting following an unexpected weather disturbance. This paper reveals firstly a medium term forecasting (MTF) of irradiance and ambient temperature relying on their behaviours during the days before. This task is ensured by a neuro-fuzzy estimator. The obtained MTF is modelled by an Auto-Regressive Moving Average (ARMA). A Kalman filter provides short term forecasting (STF) using the ARMA model and the measured data of meteorological parameters since sunrise. Once entered to an input/output solar plant model, the proposed MTF and STF models allow daily and instantaneous realistic forecasting of the plant energy supply. The developed models have been tested and validated by analysing the normalized root mean square error (NRMSE) and the normalized mean bias error (NMBE).

2. The estimator principle

The meteorological estimator consists of two types of dynamic forecasting:

- MTF : it delivers an estimated time distribution for the day (d) of irradiance ($\tilde{I}_{\mathrm{mf}}(d,t)$) and ambient temperature ($\tilde{T}_{\mathrm{mf}}(d,t)$).
- STF: it gives, during the same day d for a time step assumed to be 5 min, the real time forecasting of irradiance ($\hat{I}_{\mathrm{sf}}(d)_{k+1|k}$) and ambient temperature ($\hat{T}_{\mathrm{sf}}(d)_{k+1|k}$, Fig. 1).

The MTF consists of Gaussian distributions of the cumulated irradiance $\tilde{G}(d)$ and the maximum and minimum ambient temperatures ($\tilde{T}_{\max}(d), \tilde{T}_{\min}(d)$) during the day d, which are represented by the vector $\tilde{E}(d)$. $\tilde{E}(d)$ is estimated on the basis of the meteorological behaviour during the last 20 days DB($d-1$), using a neuro-fuzzy estimator. A Kalman filter provides the STF by carrying out the MTF from the ARMA model and by considering the k last measurements of meteorological parameters represented by $Y(d,k)$ which are taken during the same day d.

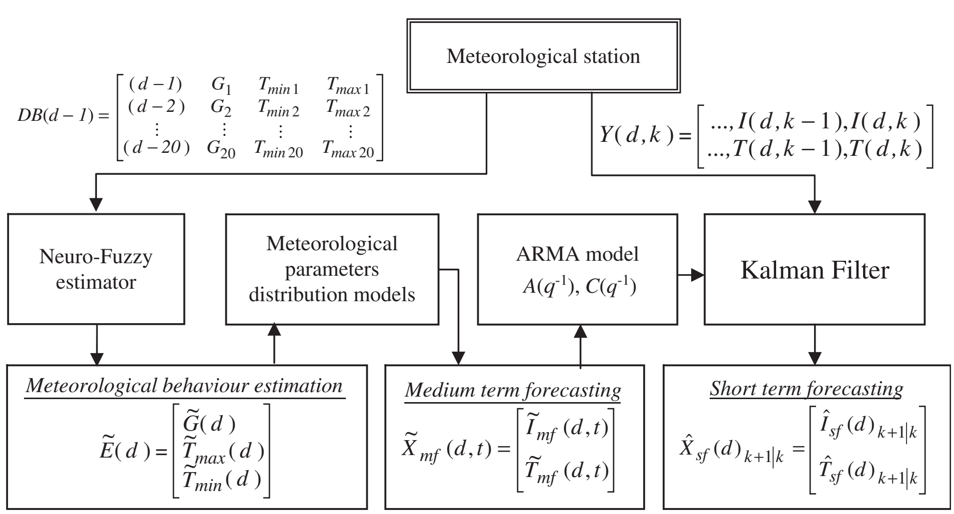

Fig. 1. Medium and short term forecasting principle.