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Measurements based dynamic climate observer

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Abstract

This paper introduces a dynamic prediction of solar radiation and ambient temperature. Medium term prediction is based on climatic parameters behaviours during the day before and on time distribution models. As for short term prediction, it is ensured by an ARMA predictor using Kalman filter. Herein, we describe our method and present prediction results. Validation is based on measures taken during the year 2005 in the north of Tunisia. The work effectiveness is illustrated by a short term and medium term prediction of the electric energy produced by a 1 KWp photovoltaic panel (PVP) installed at the Energy and Thermal Research Centre (CRTEn) in the north of Tunisia. Since our work delivers accurate climatic parameters prediction, the obtained results can be easily adapted to predict any other solar conversion system output.

Keywords: Climatic parameters; Prediction; Modelling; Kalman filter; Photovoltaic

1. Introduction

Accurate prediction of climatic parameters behaviour during daylight is a prerequisite in most solar energy applications particularly in design methods, system characterisation and decision making for energy management. Different models were introduced in literature so as to predict climatic parameters. Myers (2005) proposed a simplified solar radiation model for renewable energy applications. More complex modelling methods gave empirical models (Li Danny and Cheung Gary, 2005) or spatial and temporal variations (Chaâbane et al., 2004). Measurements based models were also proposed using either METEOSAT images (Chaabane and Ben Djemaa, 2002) or measured meteorological variables (de Miguel and Bilbao, 2005). Recent methods for Forecasting daily total solar radiation were introduced such as adaptive wavelet-network (Mellit et al., 2006) and fuzzy logic (Iqdour and Zeroual, 2006). Since these researches aimed to offer tools for solar plants sizing, they estimated yearly, monthly and daily solar radiation basing on long term data base which is not always available for all sites. Other researches used weather forecasts provided via e-mail by meteorological institutes (Prudhomme and Gillet, 2001; Pickhardt, 2000) in order to build solar plants control. Even if forecasted climatic parameters are truthful, the method remains unsuitable for all solar applications and depends on Internet connection state.

Although produced results are significant, they present many insufficiencies. First, most researches were interested in solar radiation modelling without taking into account the influence of the ambient temperature on solar plant behaviour. Second, they did not estimate correctly and easily in short term the quantity of solar energy to collect which prevents real time plant energy forecast and management. In addition, since climatic parameters are stochastic signals, the introduced methods do not provide accurate forecasting following an unexpected weather disturbance. This paper reveals firstly a medium term model that predicts a time distribution of solar radiation and ambient

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temperature considering their behaviour during the day before. Furthermore, climatic parameters models are adjusted each five minutes on the basis of their acquired values and of the last prediction errors made in order to perform a next prediction. This task is ensured by an auto-regressive moving average (ARMA) model linked to a Kalman filter. Once entered to an input/output solar plant model, the proposed models allow daily and instantaneous realistic prediction of the plant energy supply. The developed models were tested and validated during the year 2005 by analysing the normalized root mean square error (NRMSE) and the normalized mean bias error (NMBE). As an application, predicted climatic parameters have been used to estimate electric generation of a PVP installed at the Energy and Thermal Research Centre (CRTEn) in the north of Tunisia. Obtained results delivered accurate prediction of the electrical energy supplied by the PVP.

2. Climate observer approach

The climate observer consists of two kinds of dynamic predictions: a medium term prediction that delivers an estimated time distribution for the day (d) of solar radiation ($\widetilde{I}_{mp}(d,t)$) and ambient temperature ($\widetilde{Ta}_{mp}(d,t)$), and a short term prediction which gives during the same day (d) for time step ΔT assumed to 5 min, real time forecast of solar radiation ($\widehat{I}_{sp}(d)_{k+1|k}$) and ambient temperature ($\widehat{Ta}_{sp}(d)_{k+1|k}$) (Fig. 1). For the medium term prediction of the day (d), the observer needs the cumulated solar radiation and the minimum and maximum temperatures measured during the day ($d-1$) represented by the characteristic matrix $M(d-1)$. As for the short term prediction, the observer uses the results carried out by the medium term prediction and measures, represented by $Y(d,k)$, taken during the same day (d) since sunrise for a time step of 5 min.

3. Medium term prediction

Solar radiation and ambient temperature curves are estimated for the day (d) on the basis of their evolutions during the day ($d-1$) and two widely used distribution models (Chaabene and Annabi, 1997).

3.1. Solar radiation prediction model

The estimated time function of solar radiation for the day d is computed using a Gaussian distribution (Eq. (1)) in which it is supposed: $I_{max}(d) = I_{max}(d-1)$:

$$\widetilde{I}(d,t) = I_{max}(d-1)\sin\left(\frac{\pi t}{\mathrm{DL}(d)}\right), \tag{1}$$

where t is the time ($t = 0$ at sunrise), $\mathrm{DL}(d)$ is the day length of day d and $I_{max}(d-1)$ is the value of $I(d-1,t)$ at $t = \mathrm{DL}(d-1)/2$. Since the amount of solar energy $G(d-1)$ is obtained by integrating $I(d-1,t)$ over the day-light of the day ($d-1$),

$$G(d-1) = \int_0^{\mathrm{DL}(d-1)} I_{max}(d-1)\sin\left(\frac{\pi t}{\mathrm{DL}(d)}\right)\mathrm{d}t, \tag{2}$$

this yields:

$$I_{max}(d-1) = \frac{\pi G(d-1)}{2\mathrm{DL}(d-1)}. \tag{3}$$

The amount of solar energy collected during the day before ($G(d-1)$) is provided by a weather station. The day length $\mathrm{DL}(d)$ is computed by:

$$\mathrm{DL}(d) = \mathrm{GMT}_{sunset}(d) - \mathrm{GMT}_{sunrise}(d), \tag{4}$$

$$\mathrm{GMT}(d) = 12 - Te(d) + \frac{L + \in \cos^{-1}(tg\delta(d)tg\phi)}{15}, \tag{5}$$

$$\mathrm{Te}(d) = 0.123\cos(N(d)+87) - \frac{\sin(2(N(d)+10))}{6}, \tag{6}$$

$$\delta(d) = 23.45\cos(N(d)+10), \tag{7}$$

$$N(d) = 0.988[D(d) + 30.3(m(d)-1)], \tag{8}$$

where $\mathrm{GMT}(d)$ is the sunset and sunrise hours of the day (d) with $\in = -1$ for sunset and $\in = +1$ for sunrise, L is the longitude, ϕ the latitude, $\mathrm{Te}(d)$ the time equation (in hour), $\delta(d)$ the declination (in degree), $D(d)$ the day of the month, $m(d)$ the month number (January = 1), and $N(d)$ the number of the day for the month.

3.2. Ambient temperature prediction model

The weather station delivers the minimum and the maximum of ambient temperature ($\mathrm{Ta}_{min}(d-1)$, $\mathrm{Ta}_{max}(d-1)$) registered

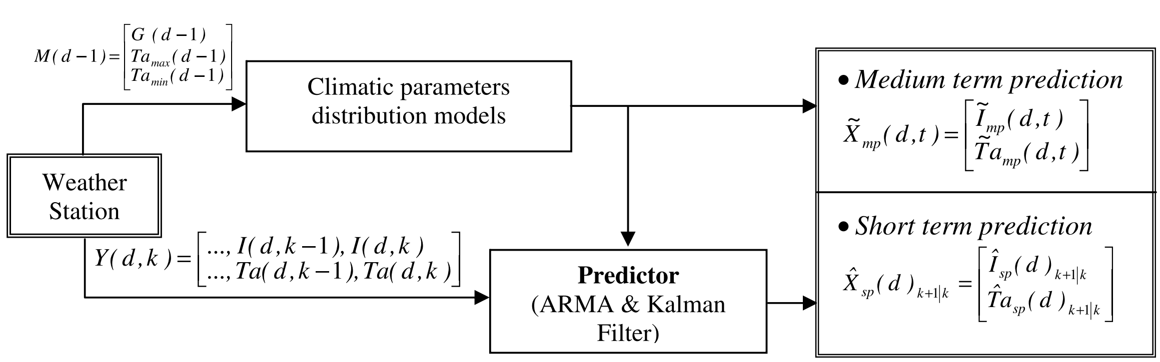

Fig. 1. Medium and short term prediction principle.