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Artificial neural network modeling and sensitivity analysis for soiling effects on photovoltaic panels in Morocco

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ABSTRACT

In the present work, an Artificial Neural Network (ANN) methodology for studying and modeling the soiling effect on solar photovoltaic (PV) glass is presented. To perform the study, a solar PV glazing was exposed outdoor at the home solar energy platform of Physic of Semi-conductors and Solar Energy research structure (PSES) at Mohammed V University in Rabat, Morocco. Regular measurements from April 20, to December 31, 2016, were carried out to monitor the soiling rate changes over time. Meteorological data were used as input variables for ANN modeling. The model performance was evaluated using a statistical comparison between experimental and simulated values. Results show that the implementation of Levenberg-Marquardt backpropagation algorithm, and the active functions Tansig, and Purline achieve the best estimations ($R^2 = 0.928$) in an ANN architecture 6-35-1. Additionally, a sensitivity analysis approach was employed to determine the effect of input parameters on model output and the behavior of the model with the variation of each input parameter. Sensitivity analysis results indicate that the most influential parameter for PV soiling rate was the relative humidity, followed by wind direction. The ANN model coupled with sensitivity analysis show be a promising framework for its application in smart sensors on cleaning systems for PV modules to improve their operational efficiency.

1. Introduction

Morocco is considered the largest potential markets for renewable energies in the region of Meddle East and North Africa (MENA), thanks to excellent solar resources throughout the country and wind resources along Atlantic Coast [1]. The potential of solar energy in Morocco is estimated at 3000 h/year, hence the launch of the Moroccan Solar Plan to reach 2 Gigawatts by 2020. Unfortunately, the sites where the solar energy is important, characterized, in most cases, by harsh weather conditions which can increase the probability of material degradation and also provoke severe dust accumulation [2]. This last parameter

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is named soiling or dusting and it is mostly a mixture of small amounts of organic particles and/or minerals from geomorphic fallout such as sand, clay, or eroded limestone.

In Morocco, just a few studies have been conducted in order to study the effect of this phenomenon on the performances of PV (Photovoltaic)/CSP (Concentrated Solar Power) modules and systems. Table 1 presents a summary of the studies performed in Morocco, their locations as well as their results. From this, it can be clearly seen that six studies have been conducted in eight Moroccan cities belonging to semi-arid, arid, and extremely arid climates. They all proving the relevance of the topic considered in this work. The studies include the losses during the exposure period, the effect of tilt angle, the determination of factors affecting soiling, and modeling of this phenomenon using time series. It can also be seen that modeling of soiling phenomenon in Morocco still need more studies, which prove that each addition in that subject will be of such importance.

Soiling is depending on several parameters which have a double effect in most cases. These parameters can be gathered into five different groups: the nature of the surface, the weather conditions, the soiling properties, the exposure conditions, and the environmental conditions. Table 2 summarizes the various parameters as well as their effects on soiling. In this table we have tried to describe for each condition (higher, lower, big, small…) of each factor (wind speed, rainfall, tilt angle…) the nature of its effect, positive (+) or negative (−). We have also described the arguments behind this nature based on studies published in literature.

The content of this table shows the complexity of the soiling phenomenon because of depending on several environmental parameters at the same time. It is also proving that extensive investigations should be conducted with the objective to understand well this phenomenon.

The parameters mentioned in this table could be divided into two categories, static parameters and temporal parameters. The static parameters depend on recommendations of standards (nature of the surface, tilt angle), physical laws such as gravity (location) or the existing specifications of the chosen site (soil texture). The temporal parameters comprise weather conditions and soiling properties and they changed through time and differ from a season to another. Concerning the tracking it is a parameter that change through the day and from a season to another but it can be considered as static from a year to another. For birds dropping, it's a complex parameter that is difficult to predict. From this we can conclude that the weather conditions and soiling properties are the most relevant parameters affecting this phenomenon. Based on this conclusion we have tried to predict the effect of soiling from some weather conditions factors. Some of them, have been chosen from Table 1 and other ones have been added in order to study their effect. The soiling properties and other parameters will be included in the future improved model.

It is extremely difficult to study experimentally the PV panel losses due to soiling everywhere, and there is an urgent need to model this phenomenon using appropriate innovative approaches. Indeed, many countries are giving a high priority to developing accurate soiling loss modeling and forecast soiling effect over time. In the last years, Artificial Neural Networks (ANN) have been employed as a suitable tool for modeling phenomena in PV systems, due to their robustness, noise tolerance and their ability to work with multivariable and non-linear information. These techniques have been successfully applied on PV systems for various purposes such as model the performance and the daily PV energy power production [17,18]; temperature estimation for PV modules and PV arrays [19,20]; modeling of characteristic curves for the development of new PV semiconductor materials [21,22]; and implementation in Maximum Power Point Tracking (MPPT) PV systems [23], to

Table 1
Studies of soiling effect on PV/CSP modules conducted in Morocco.

Category	Technology	Region	Results	Ref
Investigation	CSP	Skoura (40 km from Ouarzazat)	The soiling rate is a function of the variation of the wind speed and the relative humidity during the exposure.	[3]
	CSP	Oujda	The drop in cleanliness is: - 45% and 33% for glass and mirrors in aluminum, respectively in a horizontal position. - 14% for both reflectors at an angle of +45°. For mirrors installed at 0° and −45° angles remained clean with a purity average of about 97% for both types of mirrors.	[4]
	PV-modules irradiation sensors	Atlantic Ocean	The efficiencies dropped to 20% of the initial values within 5 months.	[5]
	CdTe PV	Marrakech, Ouarzazate, Oujda, Dakhla	Estimates of the change in average monthly CdTe PV performance due to soiling are 0 to < -3% with cleaning.	[6]
	PV/HCPV (High Concentration Photovoltaics)	Rabat	Transmittance losses of a solar PV glass due to soiling are approximately 5% per three months. Productivity losses of HCPV modules are approximately 7,64% per one month.	[7] [8]
Modeling	CSP	Tantan, Agadir	The analysis of the cleanliness of a solar reflectors exposed outdoors has been performed using the free R software for statistical computing and graphics. The results have shown that the best-fitted model describing the long-term change in the cleanliness is the local linear trend, which performs even better when an optimal discount factor of 0.95 is considered.	[9] [2]

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