Machine-Learning Based Methods for PV

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This entry presents the state of the art ML models applied in solar energy's forecasting field i.e., for solar irradiance and power production forecasting (both point and interval or probabilistic forecasting), electricity price forecasting and energy demand forecasting. Other applications of ML into the photovoltaic (PV) field taken into account are the modelling of PV modules, PV design parameter extraction, tracking the maximum power point (MPP), PV systems efficiency optimization, PV/Thermal (PV/T) and Concentrating PV (CPV) system design parameters' optimization and efficiency improvement, anomaly detection and energy management of PV's storage systems. While many review papers already exist in this regard, they are usually focused only on one specific topic, while in this paper are gathered all the most relevant applications of ML for solar systems in many different fields. It gives an overview of the most recent and promising applications of machine learning used in the field of photovoltaic systems.

machine learning photovoltaic solar energy forecast diagnostic MPPT

1. Introduction

ML is a subset of AI which is concerned with creating systems that learn or improve performance based on the data they use. The term machine learning was first used in 1959 by the American scientist Arthur Lee Samuel, with the following definition: "field of study that gives computers the ability to learn without being explicitly programmed".

Today, ML is ubiquitous. When we interact with banks, shop online or use social media, ML algorithms are used to make our experience efficient, easy and safe, along with learning our lifestyle-related preferences. For example, search engines on the Internet practically exploit them in many ways: the results we obtain derive from algorithms that elaborate models and patterns of use of search keys, as well as for completion suggestions. Amazon Go, the first store with no cashiers opened by Amazon in Seattle, is also based on ML and other advanced technologies. Self-driving cars, which we will soon see on the roads, use continuously improved ML models: MIT in Boston has developed a system that will allow these cars to orient themselves only with sensors and GPS, avoiding the use of maps which may simply be out of date or insufficiently detailed. ML is fundamental for data protection and fraud prevention, thanks to unsupervised algorithms that compare the access models and detect any anomalies, and it can also improve personal security, making checks at airports and places of transport more reliable and faster. Applications in the health sector will also be increasingly relevant, to obtain more accurate diagnoses, analyze the risk factors of certain diseases and prevent epidemics [1][2]. ML and associated technologies are developing rapidly, and we are just starting to discover their capabilities [3][4]. AI technologies have now also arrived in the field of renewable energy; from those, such as Google, who use them in wind farms to improve forecast data [5][6], to those who use them to increase the efficiency of solar panels [7].

Several AI and ML solutions are already available to predict wind and PV energy production, for predictive maintenance systems for wind turbines or to search for new materials for solar panels [5].

The perspective of ML applications for the development of renewable energy is almost unlimited. Many players in this market are testing innovative solutions to improve the performance of their systems. ML applications can make it possible to exploit in the best way the operation of plants, forecasting weather conditions, such as the exposure to the sun of the PV surfaces, the direction and strength of the wind in the case of wind power or rainfall for hydroelectric generators [8][9].

ML and predictive models can also help in the management of energy supply for households in cities, optimizing their distribution network [10][11][12].

According to the International Energy Agency (IEA), in the coming years, in the energy field AI will be decisive and will radically transform global energy systems, making them more interconnected, reliable and sustainable [13].

2. ML Applications

During the last several years, many papers have been published concerning ML applications in the field of solar systems. This paper presents the state of the art of recent advances in ML for photovoltaic and solar applications, which provides a broad overview of current advanced techniques to academics and practitioners. In particular, papers published in international journals from 2018 to 2021 have been taken under consideration. For the literature review step, the following search engines for research articles (journals and book chapters) have been extensively employed: Microsoft Academic, Scopus/ScienceDirect, ResearchGate and GoogleScholar.

The main contributions of entries are summarized below:

- This is the first paper, as far as authors know, which gathers only more recent and promising, in authors' opinion, applications of ML in many different fields of PV and not only in a specific one,
- For each of the fields under consideration a critical analysis is reported, highlighting the architecture/solution that, in literature, has proven to be the most suitable for that specific task,
- The pros and cons of each solution are detailed, in addition to suggesting ideas for further investigation.

The remainder of this paper is structured as follows: Chapter 2 reports a reasoned introduction about ML methods or more generally data-driven methods, Chapter 3 gathers all more recent review papers on the topics treated in this paper, Chapter 4 is devoted to the field of PV power forecasting, Chapter 5 reports recent papers concerning the anomaly detection (fault diagnostic) in PV, Chapter 6 regards ML-based methods for MPPT in PV, Chapter 7 gives an overview on the other applications of ML in PV field and finally Chapter 8 ends the paper with concluding remarks and an analysis of possible future trends.

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