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The role of artificial intelligence in photo-voltaic systems design and control: A review

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ABSTRACT

This paper is a review on the up to date scientific achievements in applying Artificial Intelligence (AI) techniques in Photovoltaic (PV) systems. It surveys the role of AI algorithms in modeling, sizing, control, fault diagnosis and output estimation of PV systems. It also summaries more than 100 research articles in the applications of AI techniques in PV research. A complete comparison between conventional and AI methods is carried out to prove the important role of the AI algorithms play PV systems. The paper compares between the reviewed works and outlines their contributions.

1. Introduction

The world energy crisis led many scientists and engineers to investigate and research renewable energy sources. This motivated many scientists to develop methods and techniques for converting sun irradiance into electricity. PV systems are built to transform sun irradiance into electrical power. The problem of photovoltaic systems is the relatively high cost of building such systems. All work done in literature is to increase the efficiency of such systems and decrease its cost. AI algorithms are proven to have an important role in enhancing the performance of PV systems. In this paper we provide a comprehensive review on the application of AI algorithms in modeling, sizing, control, fault diagnoses and output estimation of photovoltaic systems. It compares between AI algorithms and conventional algorithms for each application type. The paper shows that AI algorithms are expected to play a critical role in all aspects of PV research. Section 2 provides a review of some AI algorithms used in PV field. Section 3 discusses the importance of AI algorithms in parameter identification, optimal sizing, control, and fault diagnosis of PV systems. Section 4 provides a conclusion for the work.

2. Artificial intelligence techniques in PV systems

This section gives a brief introduction about AI algorithms and their diverse applications.

2.1. Neural Network NN

The human brain is the most powerful and efficient calculating machine with learning capabilities. It can solve real problems that the ordinary PC can't solve. This led many scientists and engineers to develop a model that emulates the brain behavior. The model consists of layers of neurons to represent the processes of the human brain. Each neuron models the behavior of the brain cell activity where it accumulates the weights input products and produces a firing action depending on this sum. There are many types of neural networks such as feed forward neural networks, hop-field neural networks,and radial basis neural networks. Neural networks have many applications in forecasting [1,2], control [3], modeling [4], and pattern classification [5]. They need a learning algorithm. The most famous learning algorithm is the back-propagation algorithm [6]. It depends on comparing the neural network output with the required output and calculating the error difference. This error is used in updating of neurons weights. Updating the neurons weights is the learning process of the neural network.

2.2. Fuzzy logic FL

Fuzzy logic theory was first introduced by Loftih A. Zadeh professor for computer science at university of California at Berkeley. Fuzzy logic mimics the method of human thinking. It depends on linguistic variables with IF-THEN rules base.

Fuzzy logic controller consists of a fuzzification block, rule based inference system, and de-fuzzification block. The fuzzification block is

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Nomenclature

ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
AFSA	Artificial Fish Swarm Algorithm
AI	Artificial Intelligence
AIS	Artificial Immune System
ANFIS	Adaptive-Neuron Fuzzy Inference Systems
BP	Back-Propagation
CSA	Cuckoo Search Algorithm
CSO	Cat Swarm Optimization
DNA	DeoxyriboNucleic Acid
FFA	Firefly Algorithm
FL	Fuzzy Logic
FPGA	Field Programmable Gate Array
GA	Genetic Algorithm
HNN	Hop-field Neural Network
HS	Harmony Search
INC	Incremental Conductance Algorithm
KNN	k- Nearest Neighbor
NARX	Recurrent NN With Exogenous Input
NN	Neural Networks
PO	Perturb and Observe
PI	Proportional Integral
PID	Proportional Integral dDerivative
PSO	Particle Swarm Optimization
PV	Photovoltaic Systems
RBF	Radial Basis Neural Network
RL	Reinforcement Learning
RMSE	Root Mean Square Error
RNN	Regression Neural nNetwork
SA	Simulated Annealing
SVM	Support Vector Machine
THD	Total Harmonic Distortion

responsible of converting input crisp values to linguistic values while the inference system determines the output linguistic variables based on the crisp values. The de-fuzzification block converts the linguistic variables to output crisp values. Fuzzy logic can be used in control for different applications such as robotics [7,8], aircraft control [9], temperature control [10], and many other control applications.

2.3. Simulated Annealing SA

Simulated annealing is an evolutionary algorithm that emulates the nature process of gradual cooling. The algorithm is used for optimization problems. The main advantage of simulated annealing over other optimization algorithms is finding a global maximum values. Simulated annealing has many applications in different fields such as image reconstruction [11], vehicle routing problem [12] and VLSI circuit partitioning [13].

2.4. Genetic Algorithm GA

Genetic algorithms mimic the natural behavior of evolution. In this algorithm there is an initial population of genes. A fitness function is calculated to find the best genes in the population. The genes with the best fitness function values are chosen to produce the next generation of genes using mutation and crossover functions. Mutation is a process of changing some genes in the DNA sequence. Crossover is the process of two chromosomes pair up and exchange segments of their genetic material. It can be used in image enhancement and segmentation [14], software testing [15], traffic signal coordination [16], unmanned aerial vehicles [17] and intrusion detection [18]. It is also used in optimizing fuzzy logic controllers and neural network controllers to do different tasks. In [19] a genetic optimized fuzzy logic controller is applied for pattern recognition.

2.5. Ant colony ACO

Ant colony algorithms were introduced in the early 1990's by colorni, dorigo and maniezzo. Ant colony are algorithms inspired by the behavior of ants for finding the shortest path for collecting the food to their nests. Ants move randomly to search for the optimum path. They lay down pheromones as they move. Finally the ants follow the path of higher density of pheromones. The Ant colony technique is used in the optimization of the vehicle routing problem [20], feature selection for pattern recognition problem [21] and optimization for web service instance selection [22]. The algorithm can be used also in multi-objective optimization problems and for virtual machine placement for cloud computing applications [23].

2.6. Particle Swarm Optimization PSO

This is an optimization algorithm inspired by the swarm and flocking of birds. It has a wide range of applications due to its simplicity, high performance, and flexibility. It simulates the behavior of a group of birds searching for food. Each bird moves in a direction based on its experience and group movements. The algorithm can solve also multi-objective functions. particle swarm optimization algorithms are used in the path planning for the UAV robots [24], digital image water-marketing [25], the management of groundwater resources [26], and the optimization of the RFID network with redundant reader elimination [27].

2.7. Hybrid techniques

These techniques combine the advantages of more than one AI algorithm. We will give a brief introduction about the most used algorithms in photovoltaic systems.

2.7.1. Adaptive-Neuron Fuzzy Inference Systems ANFIS

The adaptive-neuron fuzzy is a hybrid technique that combines the benefits of both neural networks and fuzzy logic. It can be used for forecasting the energy needs of a building in early stage of design [28], predict crop yield based on different energy inputs [29], and recently for early detection of sleep disorders [30]. The algorithm is also used for edge detection [31],and financial forecasting [32].

2.7.2. GA-fuzzy and NN-fuzzy

In this technique genetic algorithms or neural networks are used to optimize the membership degree function of the fuzzy logic controller. This is to solve the problem of trial and error needed to optimize the operation of the fuzzy logic controller. In [33] a genetic optimized fuzzy logic controller is applied in water pressure control.

3. Artificial Intelligence in PV systems

AI algorithms are used in many aspects of sizing, modeling, and controlling of PV systems. The application of artificial intelligence in PV research can be classified into five main categories as will be described in the next section.

3.1. parameters identification of solar cells model

The accurate modeling of solar cells is a critical part in photovoltaic systems research. For modeling a PV system one has to model it mathematically and then extract its parameters. There are two