Artificial Neural Network modeling of a photovoltaic module

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Outline

Introduction I

- The increasing world's energy demands, and the need of revising the energy policies in order to fight against the emissions of CO_2 and environmental pollution are some reasons for the increasing interest in the development of renewable energy sources.
- This interest has motivated research and technological investments devoted to improve energy efficiency and generation.

Introduction II

- Photovoltaic energy is a clean energy, with long service life and high reliability.
- It has been considered as one of the most sustainable renewable energy sources.
- Photovoltaic systems may be located close to the points of consumption, avoiding transmission losses and contributing to the reduction of CO_2 emissions in urban centers.

Introduction III

- Due to the high cost and the low efficiency of commercial modules (about 15%), it is essential to ensure that they work at their peak production regime.
- To reach this objective it is necessary to develop appropriate control algorithms, and to have an accurate model of the real (not ideal) photovoltaic elements behavior is mandatory.

Introduction IV

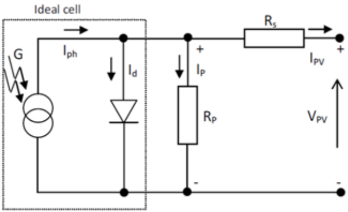
- There are a number of theoretical photovoltaic cell models.
- They are not easily fit to a given real particular cell, because parameter values are either unknown or difficult to estimate. Lack of calibration thus render these models useless.
- The main objective of this paper is to describe the process to obtain a model based on ANN training using acquired data of a real ATERSA A-55 photovoltaic module.

Section Contents

Model of an ideal photovoltaic cell

- The ideal photovoltaic cell can be modeled as an electric current source with an anti-parallel diode.
- The direct electric current generated when the cell is exposed to light varies linearly with the solar radiation.
- An improved model includes the effects of a shunt resistor and the other one in series.

Basic and improved equivalent model of an ideal photovoltaic cell



- I_{ph} is the photogenerated current or photocurrent,
- I_d is the current of the diode,
- I_P is the shunt current,
- R_S is the series resistance (Ω),
- R_p is the shunt resistance (Ω).

Typical equation model I

- Based on the relationship between the voltage (V_{PV}) and the current (I_{PV}) supplied by the photovoltaic cell of the "Ideal Photovoltaic Cell" model.
- It is a theoretical model:
  - We have to use an estimation of all the involved parameters
  - This circumstance leads only to approximate values when the study of a particular photovoltaic module is being carried out.

Typical equation model II

$$I_{PV} = I_{ph} - I_d - I_P$$

$$I_{PV} = I_{ph} - I_0 \left(e^{\frac{q(V_{PV}+I_{PV}R_S)}{aKT}} - 1 \right) - \frac{V_{PV} + I_{PV} R_S}{R_P}$$

where:
I_0 is the saturation current of the diode (A),
q is the charge of the electron, 1.6×10^{-19} (C),
a is the diode ideality constant,
K is the Boltzmann's constant, 1.38×10^{-23} (j/K),
T is the cell temperature (ºC).

Characteristic curves I

- Theoretical model are the I-V curves provided by manufacturers.
- They give the manufacturer's specification of the relation between the current (I_{PV}) and the voltage (V_{PV}) supplied by a particular photovoltaic module.
- I-V curves are shown for a specific temperature for a few irradiance values.
- Temperature and irradiance are relevant magnitudes in the relation between I_{PV} and V_{PV},

Characteristic curves II

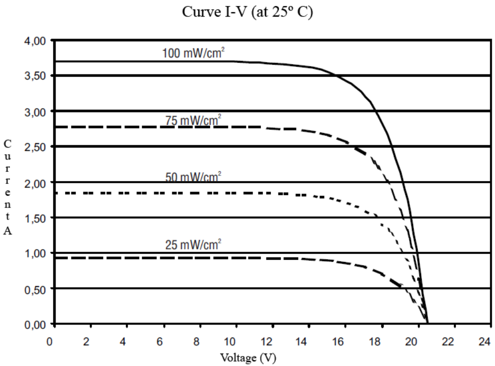


Figure: I-V curve of the Atersa A-55 photovoltaic module

Artificial neural networks

- Bio-inspired computational devices have several advantages, and among others, these are the most outstanding to our problem:
  - Learning capabilities
  - Generalization capabilities
  - Real time capabilities

Section Contents

3 Experimental design
- Photovoltaic module
- Electrical installation for data capture
- NN model generation

Atersa A55 photovoltaic module

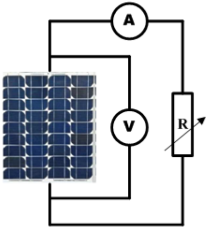
- Manufactured by Atersa, a pioneer company in Spain within the photovoltaic solar power sector, with more than 35 years of experience.

Photovoltaic module characteristics

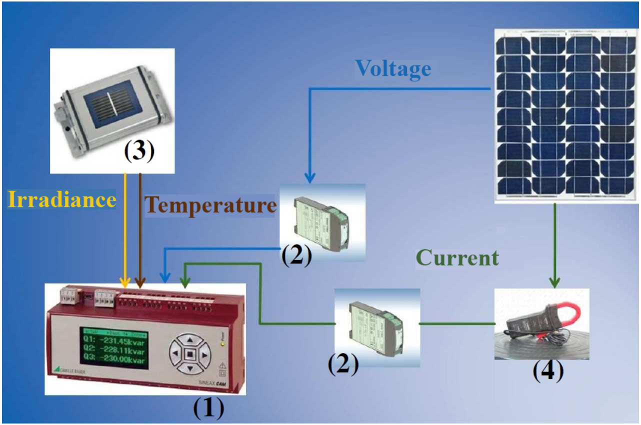
Attribute	Value
Model	Atersa A-55
Cell type	Monocrystalline
Maximum Power [W]	55
Open Circuit Voltage Voc [V]	20,5
Short circuit Current Isc [A]	3,7
Voltage, max power Vmpp [V]	16,2
Current, max power Impp [A]	3,4
Number of cells in series	36
Temp. Coeff. of Isc [mA/ºC]	1,66
Temp. Coeff. of Voc [mV/ºC]	-84,08
Nominal Operation Cell Temp. [ºC]	47,5

Conceptual disposition of measuring devices

- Voltmeter placed in parallel with the module and the amperemeter in series.
- A variable resistance to act as a variable load and obtain different pairs of voltage and current with the same irradiance and temperature.
- Temperature and irradiance depends on the climatological conditions.



Data capture devices



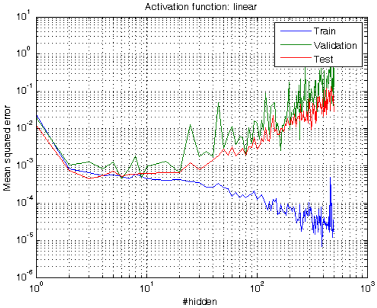
NN structure and training

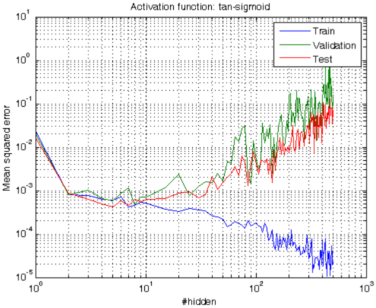
- Problem: accurate approximation of the I-V curve by an ANN
- NN structure:
  - Feedforward models
  - One or two hidden layers
  - Trained with the classical backpropagation algorithm
  - The size of the hidden layers was varying from 1 to 500 for the case of single layer, and from 1 to 100 for each layer in the case of two hidden layers
- Activation functions: For each network structure, linear and tan-sigmoid
- Five independent training/test processes have been performed for each network
- Training is performed applying Levenberg-Marquardt algorithm

Patterns

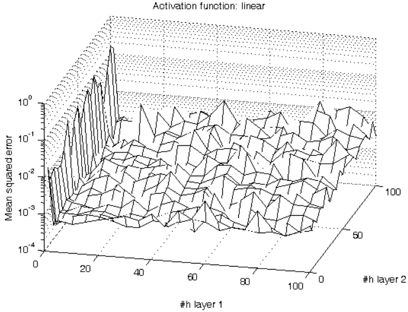
- Three single inputs:
  - Environmental temperature
  - Environmental irradiance
  - Voltage supplied by the module
- Output: the current supplied
- It is a single variable regression problem, and it involves strong no-linearities
- All the ANN input vectors are presented once per iteration in a batch
- We have used the raw data, i.e., without normalization.
- Input vectors and target vectors have been divided into three sets using random indicesllows: 60% are used for training (116 vectors), 20% are used for validation (39 vectors), and finally, the last 20% (39 vectors) are used for testing.

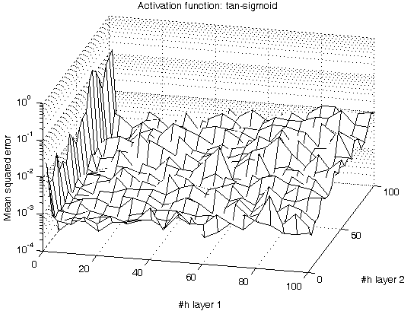
Best ANN for each structure (1 layer)



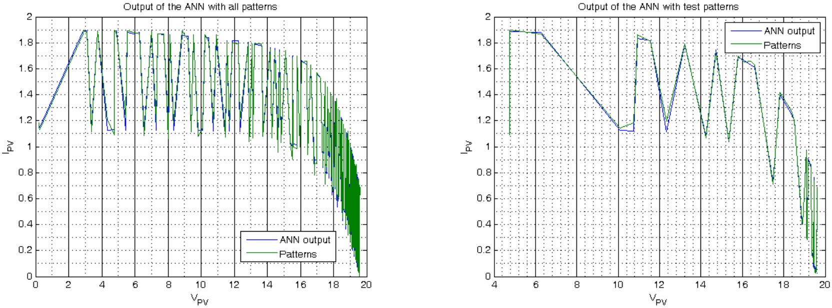


Best ANN for each structure (2 layers)

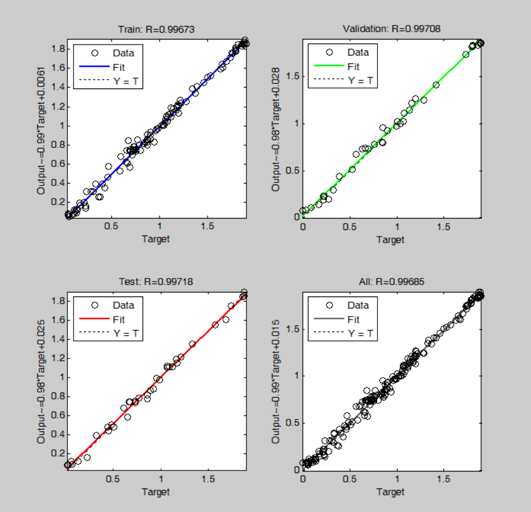




Fitting with 3 neurons single layer ANN



Correlation coefficient



Conclusions

- Designing efficient control algorithms needs accurate models of photovoltaic modules.
- Obtaining an accurate model of a real photovoltaic module is still an open issue.
- Our approach: ANN models as approximations to the characteristic I-V curve of a given module.
- Encouraging test results:
  - Very simple network structure and very fast response.
  - MSE below 3.10^{-4} on independent test dataset.
  - The accuracy and generalization capability of the model has been verified.

Future work

- We plan to gather more experimental data under a variety of environmental conditions different from the winter conditions of the data reported in this paper.
- A broader range of temperature and irradiance values will improve generalization of the ANN model.

Thanks for your attention.