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Synthetic Series of Electricity Generation through a Photovoltaic System by using Different Panel Temperature Models

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Abstract

The present work aims to compare some photovoltaic panel temperature models and the electrical energy produced from a photovoltaic system located in the Midwest area of Brazil. The applied methodology aims, through the evaluation of the expected averages and standard deviations of the synthetic series of generated energy, to identify the main random variables that influence the electric generation. The results indicate the model that best describes the physical system in relation to the photovoltaic technology, the location, and the measurement period considered.

1. INTRODUCTION

- Photovoltaic solar energy is the fastest growing energy source in the world, with an increase of 31.2% from 2017 to 2018 [1].
- The **electrical energy supplied by photovoltaic panels** is a function of the **solar irradiance** and the **module temperature** [2].
- There is great difficulty in predicting the energy generated by photovoltaic systems over the project life. Panel temperature and power output depend on several stochastic factors, such as **solar irradiance**, **ambient temperature**, **wind speed**, humidity, and **wind direction**.
- **Panel temperature can be predicted by several models**. This work compares the performance of the models presented by Masters [3], Pinheiro Neto et al. [4], and Tamizhmani et al. [5].
- This study aims to fill the gap in the **small number of studies** that consider the **random variables** to estimate the **electricity generated from photovoltaic systems** during the project lifetime.

2. METHODOLOGY

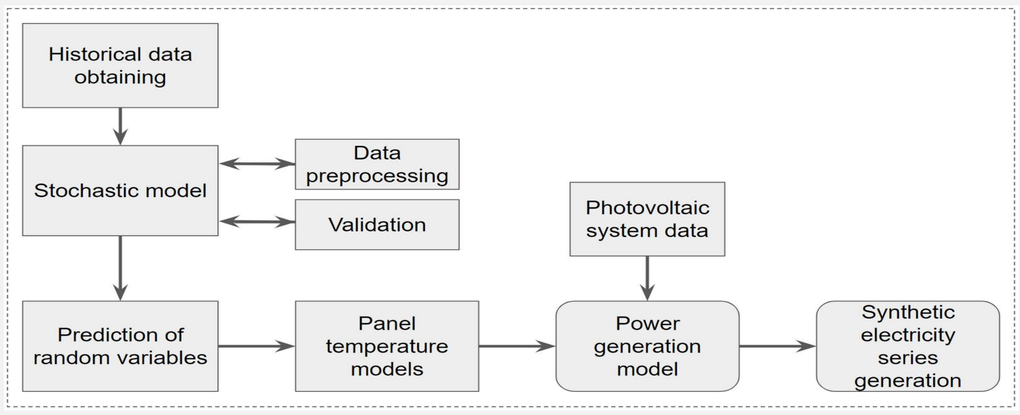

Fig. 1 - Flowchart of the methodology.

- Autoregressive stochastic model: $z_i = a_1 z_{i-1} + a_2 z_{i-2} + \cdots + a_k z_{i-k} + c + e_i$
- Data preprocessing: $t_i = \frac{1}{N}\sum_{j=1}^{N} x(i,j)$ $\quad x'(i,j) = \frac{x(i,j)}{t_i} - 1$
- Model validation: $MPE = \frac{100}{n}\sum_{j=1}^{n} \frac{|y_j - \hat{y}_j|}{y_j}$
- Panel temperature model A: $T_{PA} = T_a + 0.03125 \cdot I$
- Panel temperature model B: $T_{PB} = 0.926 \cdot T_a + 0.03 \cdot I - 1.666 \cdot W + 5.1$
- Panel temperature model C: $T_{PC} = 0.954 \cdot T_a + 0.03 \cdot I - 1.629 \cdot W + 0.088 \cdot H - 0.005 \cdot W_{dir} + 3.9$
- Power generation model: $P_{panel} = \frac{I}{I_{STC}} P_{max_{STC}} [1 + \gamma_T (T_{panel} - T_{STC})]$

3. RESULTS

- The historical data of the climatological variables was obtained from the National Solar Radiation Database (NSRDB) for a photovoltaic system installed at Itumbiara IFG campus.
- The parameters of the AR model for each variable were estimated using the maximum likelihood method [5],[6].

Table 1. - Estimated parameters of the AR model for each variable.

Manufacturer	**Canadian Solar**
Model	**CS6P-270P (Polycristallyne)**
Peak Power (Wp)	**270**
Number of Panels	**80**
Azimuth Angle (º)	**130**
Tilt Angle (º)	**7**
Performance Ratio (PR)	**75%**
Long-term Degradation	**0.75% (per year)**
Temperature Coefficient (Pmax)	**-0.41%/ºC**

Table 2. - Estimated parameters of the AR model for each variable.

	I	**T_a**	**W**	**H**	**W_{dir}**
k	9	1	1	1	12
a_k	0.1405	0.2904	0.1964	0.2888	-0.1904
c	-1.73e-5	1.16e-5	-7.65e-5	5.31e-5	7.55e-4
Var	0.0041	0.0012	0.0091	0.0085	0.0228

- It was generated 2000 scenarios of the synthetic series of the random variables for the entire period of the historical data, which was 20 years.
- Historical series and synthetic series were compared with each others in relation to their averages, standard deviations, minimum and maximum, and the Mean Relative Percentage Error (MPE).

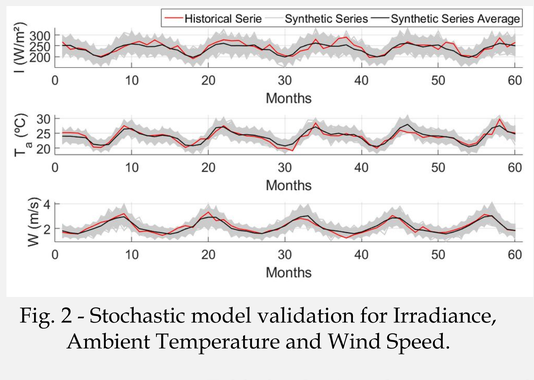

Fig. 2 - Stochastic model validation for Irradiance, Ambient Temperature and Wind Speed.

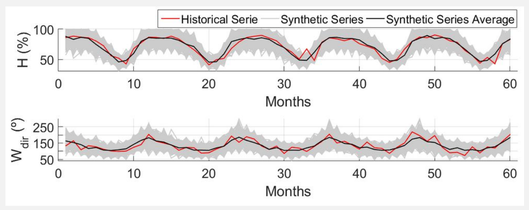

Fig. 3 - Stochastic model validation for Humidity and Wind Direction

Table 3. - Statistical parameters of the synthetic series for each variable.

	I (W/m²)	**T_a (ºC)**	**W (m/s)**	**H (%)**	**W_{dir} (º)**
Min	171.8	19.22	1.26	37.69	67.08
Max	297.1	28.85	3.54	99.99	239.4
Mean	236.7	23.75	2.14	71.46	134.4
Std	20.83	1.88	0.46	14.48	25.56
MPE	5.05%	3.02%	7.92%	7.4%	12.99%

- The values of panel temperature measurements were obtained from 01/17/2018 to 04/16/2019, corresponding to 16 months.

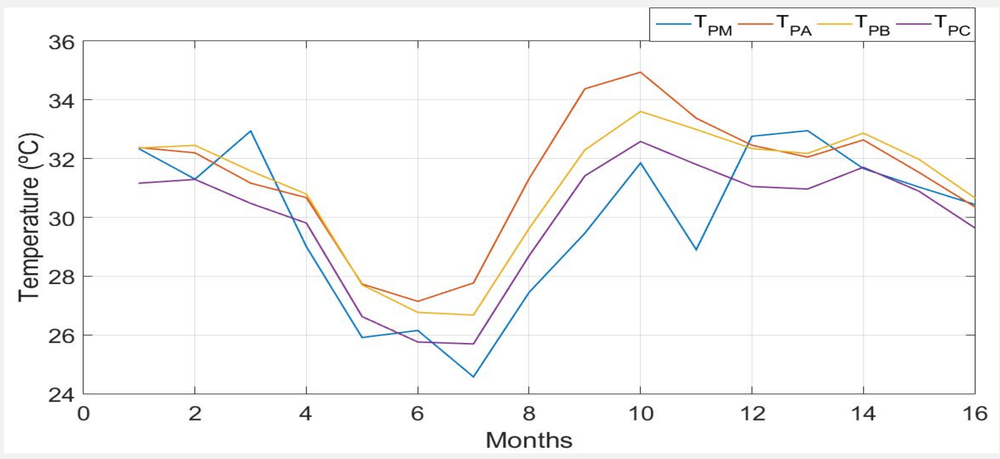

Fig. 4 - Measured and calculated panel temperature

- The global average of the measured panel temperature is 29.92 °C.
- The averages of the calculated panel temperatures using models A, B and C over the same period are: 31.42 °C, 30.88 °C and 29.82 °C, respectively.
- The average errors are 5.73%, 4.67% and 3.77% for models A, B, and C, respectively.

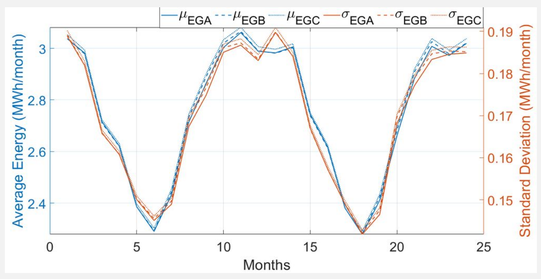

Fig. 5 - Monthly averages and standard deviations of generated energy for each temperature model

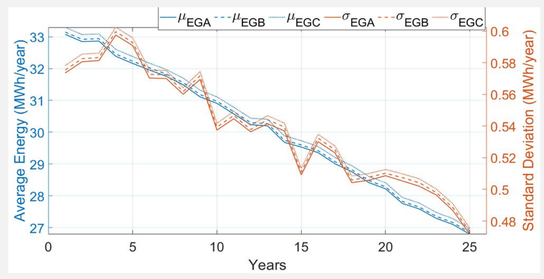

Fig. 6 - Annual average and standard deviations of generated energy for each temperature model

- The decrease in generated energy found in Fig. 6 is due to the degradation of the panels efficiency over time.
- The global averages of the synthetic series of energy generated over the project lifetime for each model are: 2.511 MWh/month, 2.516 MWh/month, and 2.528 MWh/month, respectively.
- The global averages of annual generated energy calculated for models A, B and C are: 30.129 MWh/year, 30.197 MWh/year, and 30.332 MWh/year, respectively. From model A to model B there is 0.22% increase in the yearly average energy generated over the project life. From model B to model C, there is 0.45% increase in the yearly average energy generated.

4. CONCLUSION

- The stochastic autoregressive model allowed the prediction of the random variables solar irradiance, ambient temperature, wind speed, relative humidity, and wind direction over the project lifetime. The prediction series were, then, used in panel temperature and power generation models to obtain the synthetic series of electricity generated by the photovoltaic system.
- Panel temperature measurements were also performed from a photovoltaic system located in the city of Itumbiara, in the Midwest region of Brazil.
- Validation results from both averages and errors indicated that the panel temperature model that came closest to the measurement data was Model C, which incorporates solar irradiance, panel temperature, wind speed, relative humidity, and wind direction. Model A, which considers only the solar irradiance and the ambient temperature, had the worst performance, with the furthest averages from the measurements and the largest error. Model B, which considers the irradiance, the ambient temperature, and the wind speed showed intermediate performance.

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