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Choice of the Best Production Prediction Model for the Zagtouli Solar Power Plant in Burkina-Faso

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Abstract

In this paper, we present a study on the prediction of the power produced by the 33 MWp photovoltaic power plant at Zagtouli in Burkina-Faso, as a function of climatic factors. We identified models in the literature, namely the Benchmark, input/output, Marion, Cristo-fri, Kroposki, Jones-Underwood and Hatziargyriou prediction models, which depend exclusively on environmental parameters. We then compared our linear model with these seven mathematical models in order to determine the most optimal prediction model. Our results show that the Hatziargyriou model is better in terms of accuracy for power prediction.

Keywords

Model, Prediction, Power, Power Plant, Photovoltaic, Zagtouli, Burkina-Faso

1. Introduction

The global energy context is marked by a reduction in conventional fossil fuels and greenhouse gas emissions [1]. The development of renewable energies remains the most effective response. The use of these energies is an environmentally-friendly solution to global energy demand and can provide significant reductions in carbon emissions and environmental pollution [2] [3]. One of the fastest growing renewable energies in terms of installed capacity is solar photovoltaics.

In 2022, the world's cumulative installed solar PV capacity is estimated at 1170 GW. This capacity has increased by 420 GW, making an installed capacity of 1590 GW at the end of 2023 according to the International Energy Agency.

Among renewable energies, photovoltaic (PV) solar energy is of particular interest to Africa, as it has a solar deposit that is ideal for the development of this energy source. Burkina Faso enjoys a high potential for sunshine, with more than 3000 hours of sunshine a year, representing a solar energy potential of around 5.5 kWh/m^2/day, with almost constant sunshine throughout the year. Despite this unrivalled competitive advantage, Burkina Faso imports more than 60% of its electricity from neighbouring countries, making electricity expensive and difficult for the population to access [4] [5].

In the future, Burkina Faso will no longer be able to rely on its neighbours, given the population explosion in energy consumption and the rate of urbanisation. To meet the growing annual demand for electricity (around 13% per year) due to strong demographic growth, the electrification of villages and the demands of the ongoing industrialisation of the country, the Zagtouli photovoltaic power plant was set up to alleviate this problem and reduce Burkina Faso's dependence on its neighbours [5]. The plant produces 33 MW of power, which is connected to the SONABEL grid. Advance knowledge of the following day's production is necessary for better management of the electricity network. In the literature, there are mathematical models (Benchmark, input/output, Marion, Cristofri, Kroposki, Jones-Underwood, and Hatziargyriou models) that predict production using environmental variables [6]-[8]. These models are non-linear and sometimes complete [9]-[11]. We will therefore design a fairly simple linear model using only two variables and compare these models to choose the best-performing one that best predicts the plant's output.

2. Description of the Zagtouli Power Plant in Burkina Faso

Table 1. PV module characteristics.

Maximum power	260 W
Nominal voltage (Vn)	30.8 V
Current at maximum power (Imp)	8.54 A
Open circuit voltage (Voc)	37.5 V
Short-circuit current (Icc)	9.06 A
Voc temperature coefficient	−0.31%/K
Temperature coefficient of Isc	0.051%/K
Temperature coefficient of Pmax	−0.41%/K
NOCT	46˚C
Cell efficiency	15.51%

The solar field at the Zagtouli power plant covers an area of 51 ha, with 12,960 polycrystalline silicon photovoltaic panels. The peak power of each panel is 260 Wp. The characteristics of the PV modules are summarised in **Table 1** [4].

The plant has a total of 466 junction boxes (BJ). It has 16 Integrated Photovoltaic Centres (IPC). Each IPC contains two In-geteam inverters, 1165TL B420 Indoor, with a power of 1163.9 kVA, for a total of 32 inverters [2]. The characteristics of the inverters are defined as follows: DC maximum voltage 1050 V, DC maximum current 2000 A, AC power 50˚C, and AC nominal voltage 420 V.

3. Description of Collection Equipment and Method for Determining Coefficients

SCADA (Supervisory Control and Data Acquisition) is a system for processing multiple pieces of information in real-time. This information is gathered by various sensors placed at precise locations, providing information on the different currents and energies produced by the inverters of each IPC. The weather stations are installed in 4 locations around the power station:

- 03 are installed on IPC 2, 10 and 16;
- 01 is installed on the delivery substation.

They are distributed throughout the power plant at remote points to ensure the widest possible range of measurements. The pyranometers installed on the IPC are inclined at 15˚ to measure sunshine. The pyranometer at the delivery station is horizontal. The weather stations are also equipped with sensors to measure wind and temperature [4].

To find the different coefficients of the models, we can use a non-linear regression method to fit the different models.

We will use the non-linear least squares method to find the coefficients. The non-linear least squares method consists of minimising the sum of the squares of the differences between the observed values (the existing data) and the values predicted by the model.

We will use the curve_fit function in the scipy optimize library on Python to perform this task.

4. Environmental Models for Power Prediction

4.1. Benchmark Model (MOD1)

Benchmark's mathematical equation [6] is given by relation (1):

$$P_m = -(aG + b) * T_c + cG + d \tag{1}$$

With: P_m: The maximum power produced (W); *G*: The solar irradiance on the inclined plane (W/m^2); T_c: The temperature of the module, which varies as a function of illuminance and ambient temperature; *a*, *b*, *c*, *d*: positive constants that can be obtained experimentally, it can be used to calculate the maximum power supplied by a module using temperature and solar irradiance. This model was developed and validated by Lu Lin in 2004.

We found the following coefficients with the actual data from our PV plant: $a = 0.30444$; $b = 11.59907$; $c = 808.95077$ and $d = 889.52767$.

4.2. Input/Output Power Model (MOD2)

This model also uses environmental parameters such as irradiation and module temperature. It also gives the power output as a function of the surface area of the installation [6]. The power at the input of the modules is given by Equation (2):

$$P_e = S * N * G \tag{2}$$

The maximum power at the output of the modules is given by Equation (3):

$$P_m = \eta * S * N * G \tag{3}$$

$$\eta = \eta_r * \left(1 - \gamma\left(T_c - T_0\right)\right) \tag{4}$$

η is the instantaneous efficiency given by the relationship; S (1016.66 m^2) is the surface area of the solar module on the inclined plane (m^2); N is the number of modules making up the PV array; η_r the reference efficiency of the module under standard conditions (T = 25˚C, G = 1000 W/m^2 and AM1.5); γ is the temperature coefficient (˚C) determined experimentally, defined as the variation in module efficiency for a 1˚C variation in cell temperature. These values vary between 0.004 and 0.006 (˚C).

With our real data, we find the following coefficients: $\eta_r = 0.1515$ and $\gamma = 0.0052$.

4.3. Marion Model (MOD3)

Marion's model is a simple linear model that gives the maximum power produced as a function of environmental parameters and the reference power given by the manufacturer under standard conditions. It also depends on the coefficient of variation of efficiency as a function of temperature [6]. The equation for Marion's model is given by relationship (5):

$$P_m = P_{m,ref}\left(\frac{G}{Go}\right) * \left(1 - \gamma\left(T_c - T_0\right)\right) \tag{5}$$

With: γ (0.0052) the coefficient of variation of efficiency as a function of temperature; $P_{m,ref}$ (The maximum value, equal to1085.76 kWc): Reference power in C.T.S.; *To*: Reference temperature in C.T.S (25˚C); *Go* The value of the reference insolation is equal to 1000 W/m^{2}.

4.4. Cristofri Model (MOD4)

This model, like the previous ones, predicts the maximum power produced by one or more modules, taking into account irradiation, module temperatures and efficiency [6]. We therefore have Equation (6):

$$P_m = S * G * \eta_r * (1 - \gamma * \left(T_c - T_0\right) + \gamma_c * \log\left(\frac{G}{G_0}\right) \tag{6}$$

where η_r the reference efficiency in STC conductors; *Tc* the cell junction temperature expressed in ˚C; T_o the reference temperature taken equal to 25˚C; γ_c:

Correction coefficient with respect to illuminance G (γ_c = 0.0053/˚C for c-Si: 0.004 - 0.006/˚C); We find γ_c 0.0053/˚C; γ the coefficient of variation of efficiency as a function of temperature and its value is between 0.004 and 0.006 (˚C) for Silicon; S (1016.66 m^2) the surface area of the module.

4.5. Kroposki Model (MOD5)

According to the Kroposki model [6], the calculation of maximum power is based on meteorological data and data supplied by the manufacturer. The mathematical expression of this model is defined as follows:

$$P_m = P_{m,ref} * \left(\frac{G}{G_0}\right) * \left(1 + \alpha_0 * \left(T_c - T_0\right)\right) * \left(1 + \beta_0 * \left(T_c - T_0\right)\right) * \left(1 + \gamma_c \log\left(\frac{G}{G_0}\right)\right) \quad (7)$$

Avec: α_0 (0.051%/K) le coefficient de courant en fonction de la température (A/˚C); β_0 (−0.31%/K) le coefficient de la tension en fonction de la température (V/˚C); γ_c le coefficient de correction par rapport à l'éclairement G; T_c la température de la cellule; G_0 l'irradiation dans les STC; et G l'irradiation solaire.

4.6. Modèle de Jones et Underwood (MOD6)

First proposed by Jones and Underwood in 2000, this is a logarithmic model whose maximum power is calculated using formula (8) [6]:

$$P_m = FF * \left(I_{cc} * \left(\frac{G}{G_0}\right)\right) * \left(V_{co} * \frac{\log\left(k \cdot G\right)}{\log\left(k \cdot G_0\right)} * \frac{T_c}{T_0}\right) \quad (8)$$

Avec $k = \dfrac{I_{cc}}{G_0}$ et $FF = \dfrac{V_{mp} * I_{mp}}{V_{co} * I_{cc}}$.

The values of these coefficients are as follows: $K = 0.00906$; $FF = 0.774$; I_{cc} is the short circuit current (A), V_{co} is the open circuit voltage (V), FF is the form factor, V_{co} is the open circuit voltage, I_{cc} is the short circuit current, V_{mp} is the maximum voltage, I_{mp} is the maximum current.

4.7. Hatziargyriou Model (MOD7)

The local weather conditions and the technical characteristics of the module allow us to determine the maximum power produced by the module [6]. The equation for determining the power is given by relationship (9):

$$P_m = \left(\frac{G}{Go}\right)\left(P_{m,ref} + \mu_{p,\max} * \left(Tc - To\right)\right) \quad (9)$$

where: Tc the cell temperature, Go the irradiation in the STCs, G the solar irradiation, $\mu_{p,\max}$ (0.41%/K) the maximum power coefficient as a function of temperature, P_m, ref the reference power in the STCs.

5. Results and Discussion

5.1. Data Analysis

In **Figure 1**, the climatic parameters and power over two days show that power and sunshine are bell-shaped, indicating the daily variation in sunshine and production. There are often high peaks on both sides, indicating the daily variation in these variables.

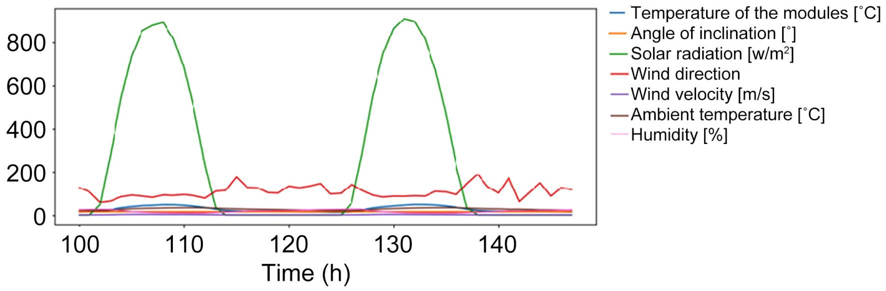
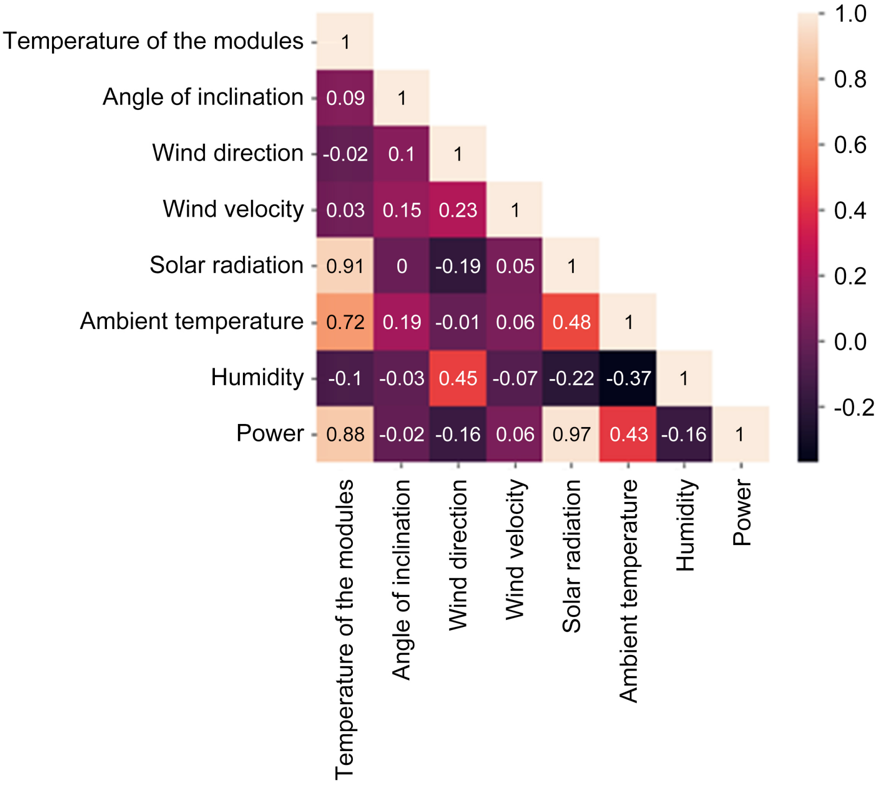


Figure 1. Curves of climatic variables over two days.

Figure 2 shows the matrix of correlation coefficients between our different variables.



	Temperature of the modules	Angle of inclination	Wind direction	Wind velocity	Solar radiation	Ambient temperature	Humidity	Power
Temperature of the modules	1							
Angle of inclination	0.09	1						
Wind direction	-0.02	0.1	1					
Wind velocity	0.03	0.15	0.23	1				
Solar radiation	0.91	0	-0.19	0.05	1			
Ambient temperature	0.72	0.19	-0.01	0.06	0.48	1		
Humidity	-0.1	-0.03	0.45	-0.07	-0.22	-0.37	1	
Power	0.88	-0.02	-0.16	0.06	0.97	0.43	-0.16	1

Figure 2. Correlation between the different variables.

Figure 2 shows a strong correlation between ambient temperature and module temperature, between power and module temperature and between power and solar radiation. In view of these different correlations, we will retain only solar radiation and module temperature as independent variables and power as the dependent variable.

5.2. Prediction Model and Model Comparison

We evaluated the resulting linear model and the metrics are given in Table 2.

Table 2. Linear model metric.

	R^2	R	RMSE
Train dataset	0.9426	0.9709	60581.6234
Test dataset	0.9420	0.9705	61025.6751

The R^2 values of the Train and Test data sets are almost equal. The model is valid at and around 94%, which means that the power variation can be explained by solar irradiance and module temperature at 94%. Figure 3 shows a representation of the power using the linear model obtained.

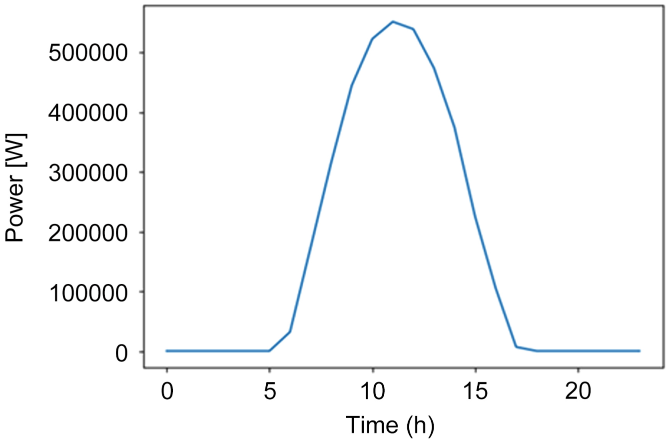


Figure 3. Linear prediction model.

Figure 4 shows the power output of different models over the course of a day.

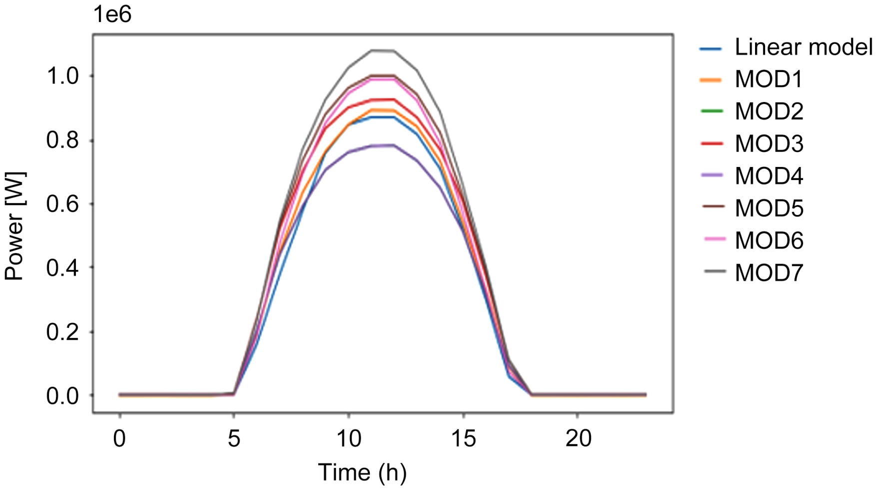


Figure 4. Comparing models.

Figure 4 shows that, generally speaking, the various curves have the same shape. From 0 a.m. to 5 a.m. and from 6 p.m. to midnight, the curves are practically linear and the power is zero. Between 5 a.m. and 6 p.m., all the curves increase and reach their maximum at 12 p.m. and 1 p.m., then decrease to zero at 6 p.m.

Models 5 and 6 are almost identical, with almost the same maximum power. Models 7 and 4 have steeper and lower curves, respectively, so they have the highest and lowest maximum power.

We also calculated the R^2 coefficient, which is Pearson's square correlation between predicted and true values, and the RMSE, which gives the model's precision. **Table 3** gives a comparison of the different models using these statistical metrics.

It can be seen that MOD7 clearly emerges as the best model given that it has an extremely low RMSE of 0.0028 and a high R2 of 0.9987. These metrics confirm that MOD7 makes very accurate predictions, with negligible errors.

MOD1 also performs very well with an RMSE of 209.13 and an R2 of 0.9996, but is outperformed by MOD7 in terms of RMSE.

The linear model, while not outperforming the others, is more simplified and involves fewer parameters.

Table 3. Metric for all models.

	MOD1	MOD2	MOD3	MOD4	MOD5	MOD6	MOD7	Linear Model
RMSE	209.13	3984.06	4718.12	3984.06	2175.07	5056.65	0.0028	7348.46
R^2	0.9996	0.9986	0.9988	0.9986	0.9997	0.9991	0.9987	0.9709

6. Conclusion

In this paper, whose objective was to predict the output of the PV plant, we first gave a detailed description of the grid-connected solar PV plant, then presented the different prediction models based on the climatic data, and a linear model was proposed. After comparing the different models using statistical metrics, it was found that the Hatziargyriou model (MOD7) performed best in predicting the plant's output. The linear model, although less efficient, offers a good compromise between simplicity and efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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