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Analysis of Meteorological Data for Photovoltaic applications in Ngoundiane's Site

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Abstract

This work is about an appropriate choice of a renewable energy source between a wind turbine and a solar power plant. The selected renewable energy source should supply electricity to a site, part of the University Alioune Diop of Bambey, in Ngoundiane, Thies region. The work is based on analysis of meteorological parameters (wind speed, ambient temperature, solar irradiation). According to this study, the use of solar energy to produce electricity in the site of Ngoundiane is very promising. Focusing on a standalone photovoltaic system seem to be the solution because solar resource is very abundant in Senegal and is easier characterized than wind resources. Moreover, photovoltaic technology is very well mastered.

Keywords: wind turbine, solar power plant, wind speed, ambient temperature, solar irradiation, standalone photovoltaic system.

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1. Introduction

The gradual disappearance and the increasing cost of fossil fuels along with global warming allow people to focus on new energies sources, which are friendly environment and inexhaustible to the human scale, to produce electrical energy. Among these energy sources photovoltaic and wind energies are the most exploited due to their relative availability throughout the world. However, issue about these kind of energies is their randomness. Indeed, the generation of electricity from photovoltaic or wind system depends on the meteorological parameters (solar irradiation, wind speed and ambient temperature) that made it difficult to control. Thus, before all photovoltaic and/or wind installation, these variables must be well characterized to facilitate the sizing which is a very important stage in the process of electrical production system design from renewable energy. Meteorological data can be displayed in the form of daily, monthly, or annual averages. In this case the uncertainty associated to these parameters is poor. A series of data recorded hourly through several years minimize the uncertainties and exhibit better the random nature of these parameters. Mulaudzi et al. [1] studied the evaluation of the global solar irradiance in the Vhembe

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district of Limpopo Province, South Africa, using three theoretical models:

- Angstrom-Prescott linear model for which the input parameters are the extraterrestrial irradiance (H0), actual and possible sunshine hours that varies from one site to another, since it is latitude-dependent;
- Hargreaves and Samani model for which the input parameters are the observed temperature data and the empirical coefficients which depend on the regions;
- Garcia model which incorporates both the regression coefficients and the observed temperature data for a given particular location.

Issues of models were compared with observed data for an area with a similar climatic condition to the one of Vhembe. Results showed that for the four meteorological stations used, the Garcia-model overestimate the global solar radiation, the Angstrom-Prescott and Hargreaves and Samani ones are more suitable for estimating global solar radiation. Nevertheless, it is preferable to use the linear Angstrom-Prescott model to estimate global solar radiation, rather than the models based on the temperature but most meteorological stations in South Africa collect temperature data.

In this study, meteorological data (wind speed, solar irradiation, ambient temperature) is under investigation. The aim is to predict the relevant system to produce renewable electricity in the Ngoundiane site. We use monthly values of wind speed, maximal and minimal temperatures of the zone of Thies for three years: 2013, 2014 and 2015 [2] and average irradiation of Ndem site in the region of Bambey, to evaluating renewable energy potential of Ngoundiane site. Ngoundiane is a county close to Bambey and Thies zones. The data from the region of Thies and the village of Ndem in the Diourbel region are used.

2. Analysis of wind speed data

Wind's power P is the speed to which energy is available and is defined as follows:

$$P = \frac{1}{2}\rho S V^3 \qquad (1)$$

Where P is the wind's power, ρ is the instantaneous density of air, S is the surface of the solar collection and V the wind speed.

If one of these parameters is increased, available wind's power will be strengthened. Nevertheless, weak variations of wind speed have a significant impact on the available power. An increasing of 25 % of the wind speed brings about almost recovered power multiplied by two [4]; which means that wind speed is a good indicator for the assessment of the wind potential for a given site. Table 1 gives monthly average values and the prevailing direction of the wind speed of the zone of Thies for three years 2013, 2014, 2015 measured by ANACIM (Civil Aviation and Meteorology National Agency).

Table 1: Monthly averages and dominant direction of wind speeds in the Thies zone for 3 years. WS: wind speed (m/s), DD: dominant direction, N: north, NE: north-east, NW: north-west

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	WS	3.7	5.0	5.0	3.9	3.7	4.1	3.9	3.6	3.9	3.4	3.6	2.9
	DD	N	N	N	NE	N	W	W	NW	NW	N	N	N
2014	WS	4.6	5.4	4.3	5.1	4.3	4.3	4.6	3.7	3.3	3.9	4.3	3.7
	DD	N	N	N	N	N	NW	W	W	W	N	N	N
2015	WS	4	4.3	5.0	4.5	4.5	4.3	3.6	3.3	3.4	3.6	4.2	4.1
	DD	NE	N	N	N	NE	NE	N	NW	NW	N	NE	NE

It is noticed that the wind direction of our considered zone varies significantly in all periods. However, directions N and NE are predominant for years 2013 and 2014, respectively and year 2015. Figure 1 gives the yearly variation of the monthly average of wind speeds of the zone of Thies for three considered years: 2013, 2014, 2015.

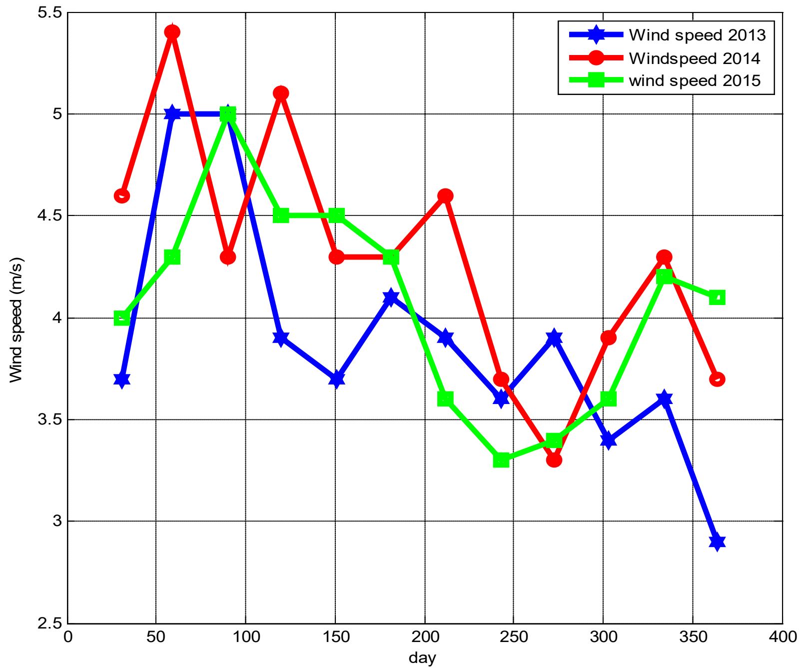

Figure 1. Annual variation of the monthly average of wind speed in the zone of Thies for years 2013, 2014 and 2015.

We remark in figure 1 that the annual profiles of monthly average wind speeds during these three years have the same way of variation. Furthermore, to the exception of the minimal speed of year 2013 which has been obtained at month of December with a value of 2.9 m/s, minimal wind speeds as well as maximal wind speeds of these years are appeared practically at the same periods with approximately close values. Indeed, minimal wind speeds of years 2014 and 2015 appear respectively at months of September and August with the same value 3.3 m/s. As to maximal speeds, they have been observed at months of February and March for year 2013 with a value of 5 m/s, at month of February for year 2014 with a value of 5.4 m/s and finally at month of March for year 2015 with a value of 5 m/s. All these data allow us to conclude that wind profile of the Ngoundiane site follows almost the same tendency. This is an asset for applications using wind energy (for example wind parks) because of the ease to make forecasts for years to come. In addition, annual average speeds of these three years 2013, 2014 and 2015 have respective values of 3.9, 4.3 and 4 m/s showing that the Ngoundiane site have an exploitable wind potential if we refer to the Senegal wind card given in [5]. In this card, the location of the most important wind potential in Senegal (between 3.8 and 4.3 m/s) is in the "grande-côte" (the seaboard in the north of Dakar).

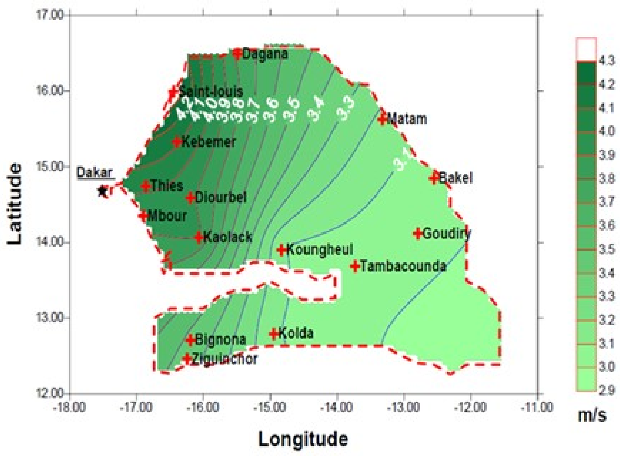

Figure 1: Senegal's wind card measured at 10 m [5]

However, the wind production's market in the whole Africa is very weak due to the high cost of the wind potential cartography. Senegal hasn't lot of experience in the domain of the wind technology compared to the photovoltaic technology. In the case of the Ngoundiane site, accurate analysis of the data show that the changes of the directions and the wind speed values are difficult to control. Indeed, for year 2013 a rather significant production could have occurred at months of February, March, April, June, July, September, because during these months, average wind speed is in the variation range (and even above for some months) of the average wind speed

obtained on the “grande-côte”. The generation of electricity for this year would be smaller during months of January, May, August, October, November, December. The same results are observed for year 2014 where important productions would have been obtained at months of January, February, March, April, May, June, July and November and the lower productions are expected at months of August, September and December. For the year 2015, the best productions would be at months of January, February, march, April, May, June, November and December and the least productions would be seen at months of July, August, September and October.
Through this analysis, we notice that periods of high productions can coincide with periods of high or low consumptions and the periods of low productions can also coincide with periods of high or low consumptions. This clearly displays the non-verifiability and the random character of the wind resources.

3. Analysis of solar irradiation and temperature data

Solar irradiation is a good indicator for estimating the solar energy potential of a given area. It is an indispensable parameter in the process of electrical system design from photovoltaic solar energy. Indeed, the daily output or energy produced by a PV module/array is expressed as follows [6]:

$$E_{PV} = A_{PV} E_{sun} \eta_{PV} \eta_{inv} \eta_{wire} \quad (2)$$

Where A_{PV} is the area of the PV module/array, E_{sun} is daily solar irradiation and, η_{PV}, η_{inv}, η_{wire} are efficiencies of PV module, inverter and wires, respectively.
Size and performance of a PV system depend strongly on the meteorological variables such as solar energy and ambient temperature. A thorough knowledge of solar radiation is needed for the sizing of a solar energy system [1].
As shown in the literature, some areas endow high intensity of solar energy. Located in the equatorial region, Malaysia naturally has an abundant sunshine and receives an average solar irradiation from 4.21 kWh/m^2 per day to 5.56 kWh/m^2 per day [7]. Kazema et al. [6] is based on the average solar radiation in Oman 5.197 kWh/m^2 per day and the daily sunshine duration between 8.0 and 10.5 h, for asserting that Oman has a very good potential for solar energy. Based on data from the hourly global solar irradiance on horizontal surface, B. Boudizi [8] shows that the Adrar region in Algeria has a higher average annual daily irradiation equal to 5.7 kWh/m^2 per day. Among various renewable energy sources in India, the solar energy is fastest growing due to its widespread availability, good solar irradiation 4.5 - 6 kWh/m^2 per day as shown by R.Rachchh et al.[9].
In our study, we use the monthly average of daily solar irradiation of Ndem site in the Bambey area (we suppose that solar irradiation's profile is invariable from year to year) for assessing the solar potential of Ngoundiane's site. These data have been obtained from the SOLARGIS* website. Figure 3 gives the annual profile of daily solar irradiation monthly average of the zone of Bambey.

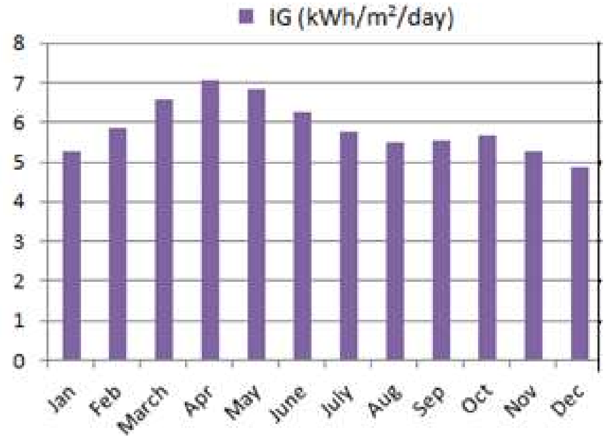

Figure 2: Annual variation of solar irradiation monthly average of the Bambey zone

Figure 3 shows important values of solar irradiation in the zone of Bambey. So, from January to April, we note an increase of solar flux, then it reduces up to month of August and then increase again up to month of October and from October the irradiation falls until December. Annual average of daily solar irradiation of the zone of Bambey is of 5.85 kWh/m^2 per day. Maximal value of irradiation is obtained at month of April with a value of 7.05 kWh/m^2 per day while minimal value is recorded at month of December with a value of 4.88 kWh/m^2 per day. We notice that annual average irradiation of the zone Bambey is very close to the Senegal average irradiation and is greater or equal to the one of the sunniest area found in the literature. We mention that Senegal has an average sunniness of 5.8 kWh/m^2 per day for a lighting of 1000 W/m^2 recorded during 3000 hours per year [5]. Results confirm the existence of a very high solar potential in the zone of Bambey. Beside of sunniness, there is the ambient temperature which has a strong influence on the PV electrical generation yield. Indeed, PV cell temperature can be estimated quite accurately with linear approximation as given by N. D. Nordin [7]. These authors [7] show that the increasing of ambient temperature involve the one of the cell and consequently

* SOLAR Geographic Information System

reduces PV cell voltage, inducing the drop of the electrical power produced by the PV generator.
In another way, variation curve of ambient and panels temperatures installed of the Ndem site is studied by [10] where it is shown that cell temperature is always superior to the ambient temperature: it is the warm-up phenomenon. This effect influences the short-circuit current and open circuit voltage and then contributes to the modification of the I-V characteristic, the fill factor (FF) and the solar cell's power output.
The following histograms give monthly variations of the ambient temperature of the zone of Thies for years 2013, 2014 and 2015 measured by ANACIM.

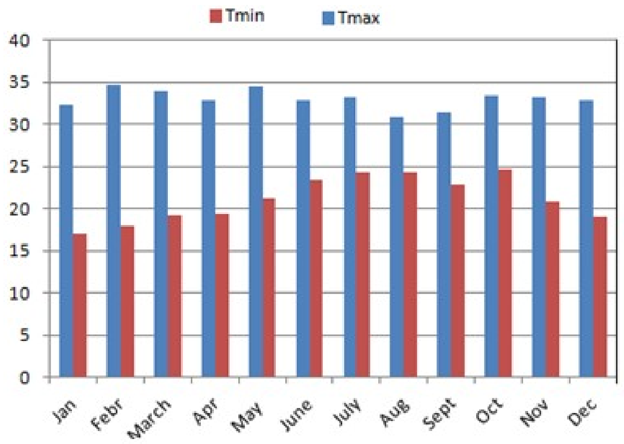

Figure 4: Annual variation of ambient maximal and minimal monthly temperatures of the Thies zone for years 2013, 2014 and 2013.

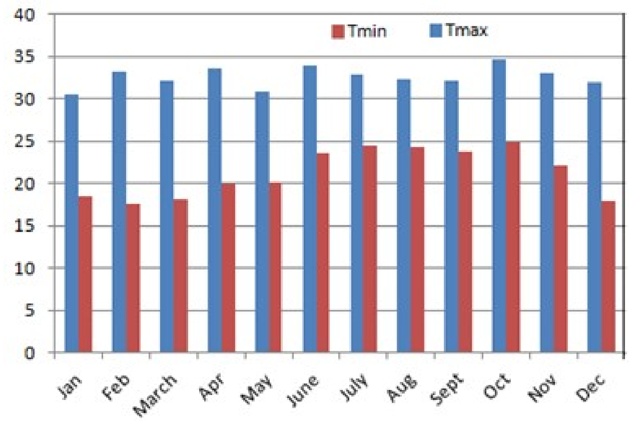

Figure 5: Annual variation of ambient maximal and minimal monthly temperatures of the Thies zone for years 2013, 2014 and 2014

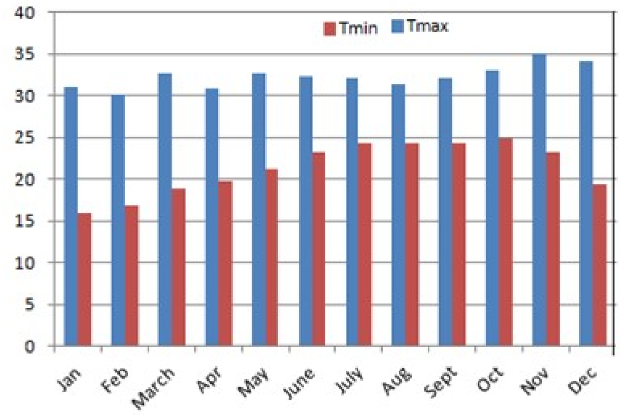

Figure 6: Annual variation of ambient maximal and minimal monthly temperatures of the Thies zone for years 2013, 2014 and 2015

These three figures show that the zone of Thies has a hot climate with maximal temperatures which can reach values going from 31.1 °C to 35.1 °C and minimal temperatures going from 16 °C to 24.9 °C. This situation lead to a lower power output of the photovoltaic module due to its negative temperature coefficient. Indeed, high operating temperatures resulting from its heating will induce of losses. That's the reason why it will be necessary to take consider the effect of the temperature in the photovoltaic production model to obtain more accurate results.

4. Conclusion

From these investigations, it is clear that it will be very difficult to control the wind electrical production and instantly to adapt it to the variation of charge because of sudden changes of the wind speed and direction values in the Ngoundiane site.
About irradiation and temperature, we saw that their annual profile is not constant. However, these parameters are easier to control than wind speed and Ngoundiane site have a powerful intensity of sunniness. Moreover, the irradiation varies slowly during time. So, use of solar energy for producing electricity in the Ngoundiane site is be very promising. It is the main reason why we put our choice in a photovoltaic solar system for supplying electricity to this site.

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