Comparative analysis of the performance of Shingle and Standard photovoltaic technologies in the environmental conditions of El Jadida

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Abstract. The objective of this paper is to evaluate the performance of two solar interconnection technologies, shingle and standard, under the specific operational conditions of the city of El Jadida, Morocco. We studied Dualsun PV modules, using shingle technology, and Almaden PV modules, based on standard technology. Performance parameters such as module temperature, efficiency and performance ratio were measured and analyzed. The results reveal that the temperature of the module using shingle technology (Dualsun PV module) is lower than that of the modules using standard technology (Almaden PV module), leading to better performance for the Dualsun PV module. In addition, the difference between the electrical efficiency of the Almaden PV module and the values provided by the manufacturer is 14.65%, while for the Dualsun module the largest difference is 12.71%. In addition, the Dualsun module has the highest average performance Ratio (90.5%), compared with 90% for the Almaden module.

1 Introduction

The solar PV energy sector is undergoing continuous expansion, supported by various regional, sub-regional and national policy programs focused on renewable energies. This growth can also be attributed to the depletion of fossil fuel resources due to rising energy demand, technological advances, falling costs of solar technologies and environmental concerns [1–3].

Currently, most solar modules on the market use crystalline H-pattern cells attached to ribbons. These cells are placed side-by-side and soldered to the ribbons for interconnection (Fig. 1 (a)), enabling cost-effective interconnection and robust technology. However, this configuration has its drawbacks, including high resistive losses and incompatibility with very thin silicon wafers. A promising new advance in module assembly is the shingled cell technique. This method consists of superimposing pre-cut crystalline cells, similar to tiles (Fig. 1 (b)) [4]. Shingled PV modules offer several advantages over standard PV modules. They feature lower ohmic losses thanks to reduced overall string current, better surface

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utilization due to the absence of gaps between cells, lower temperature processing which reduces residual stress and cell curvature, lower operating temperature which increases energy production, and improved aesthetics thanks to the absence of visible busbars and ribbons [5].

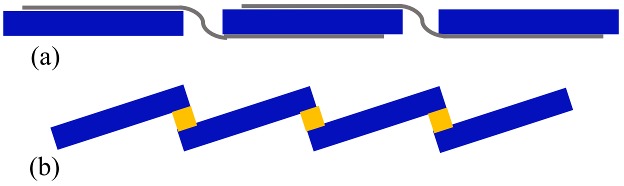

Fig. 1. schematic diagram of conventional copper ribbon interconnection (a) and shingle interconnection (b) for silicon solar cells.

Commercially available solar modules such as Dualsun [6], Solaria PowerXT® [7] and Sunpower® [8] exploit this technology to deliver higher power density. The main arguments for adopting this new design include increased power output, reduced ohmic losses due to lower currents in the module strings, absence of residual stress between silicon and metal, compatibility with thinner cells and other cell technologies, and optimization of the active surface area between cells and module. This optimization is made possible by denser cell packaging, without significantly altering the cell production process [4].

The energy efficiency of the various PV module technologies is influenced by site-specific climatic conditions, as well as by the spectral response characteristic of each technology [9]. It is therefore imperative to choose the right PV technology for local environmental conditions, a decision that requires immediate and careful attention.

The aim of this study is to compare the performance of two PV modules using different manufacturing technologies under the specific operating conditions of El Jadida. The PV modules examined are the Dualsun PV module, which uses shingle technology, and the Almaden PV module, which is based on standard technology. We will analyze the temperature distribution and performance of these two PV modules.

2 Materials and methods

2.1 Experimental setup

The experimental system (shown in Fig. 2) was installed on the laboratory roof of the Physics Department at the Université Chouaïb Doukkali (UCD) in El Jadida, Morocco. The PV modules were mounted on a stable support and oriented towards the south at an angle of 33°. The PV module types used and their specifications under standard laboratory test conditions (STC) are listed in Table 1. To measure the temperature of the front and back of the PV modules, four K-type thermocouples were used, each connected to an Arduino Mega board to record data every 15 minutes. Solar radiation was measured using an SL 200 solarimeter and a HT304N reference cell (HT Instruments). Ambient temperature was measured using a SOLAR-02 (HT Instruments), a data logger that measures solar radiation as well as ambient and cell temperatures via connected probes. The electrical characteristics of the modules, including short-circuit current, maximum current, maximum voltage, open-circuit voltage and maximum power, were determined using an I-V400w tracer (HT Instruments). This tracer enables the I-V characteristic and the main electrical parameters of a module or string of modules to be recorded in the field for PV installations up to a maximum of 1000V and 15A. Finally, a FlIR i3 infrared camera was used to visualize the temperature distribution on the two PV modules. This infrared camera has a temperature range of -20°C to +250°C, a spectral range of 7.5 to 13 µm, and an accuracy of ± 2°C or ± 2%.

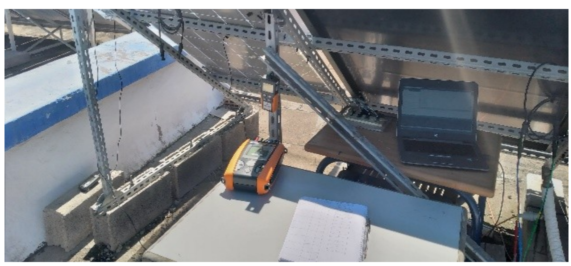

Fig. 2. PV modules and experimental setup for data acquisition.

Table 1. Technical characteristics of PV modules under standard test conditions (STC)

Parameters	**Dualsun (DSTI375G1-360SBB5)**	**Almaden (SEAC60T-300)**
Module area (m^2)	1.876	1.645
Nominal power (W)	375	300
Efficiency (%)	19.989	18.237
V_{mpp} (V)	40.4	32.40
I_{mpp} (A)	9.28	9.26
V_{oc} (V)	48.9	39.87
I_{sc} (A)	9.89	9.73
Temp. coeffi of V_{oc} (%/°K)	-0.27	-0.3
Temp. coeff. I_{sc} (%/°K)	0.04	0.06
Temp. coeff. Power (%/°C)	-0.34	-0.39

2.2 Performance analysis

The instantaneous efficiency of the PV system is defined as follows [10,11]:

$$\eta_{el} = \qquad (1)$$

Where G is the solar radiation intensity (W/ m²) and A is the surface area of the PV system (m²).
The maximum output power can be given by the equation below:

$$P_{max} = V_{oc} \,.\, I_{sc} \,.\, FF = V_{mpp} \,.\, I_{mpp} \qquad (2)$$

The performance ratio (PR) represents the ratio between the PV module's actual efficiency in operation and its efficiency under standard test conditions (STC), as shown in the following equation [1]:

(3)

The PR expresses how close a PV module is to its optimum performance under real operating conditions. It facilitates the comparison of PV systems, regardless of their location, tilt angle, orientation or power rating [1].

3 Results and discussion

3.1 Ambientes Conditions

Fig. 3 illustrates the temporal evolution of ambient temperature and solar irradiance over the course of a sunny day. From 09h41 in the morning, measurements began with a minimum irradiance of 563.8 W/m² and an ambient temperature of 25.3°C. Measurements peaked around midday. The measurement period ended at 18h11, with an irradiance of 186.4 W/m² and an ambient temperature of 26°C, as shown in Fig. 3.

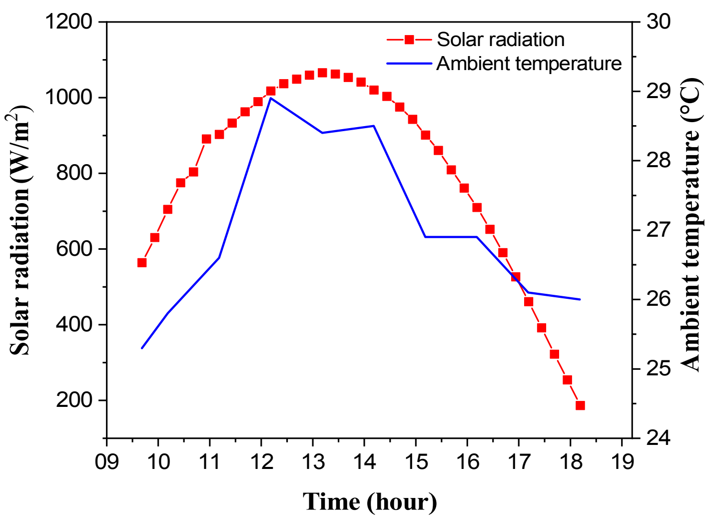

Fig. 3. Evolution of ambient temperature and irradiance over the duration of a day.

3.2 Impact of solar irradiation on the electrical performance of PV modules

The impact of variations in solar irradiance on the electrical output of Dualsun PV modules is shown in Fig. 4 (the same behavior is also observed for the Almaden module). It can be seen that electrical power increases proportionally with increasing solar irradiance. This is due to the simultaneous rise in current and voltage with irradiation. The rate of increase in current is linear and much more significant than that of voltage. At a maximum solar irradiance of 1065.8 W/m² recorded at 13h11, the electrical power of the Dualsun PV module reaches 350.81 W.

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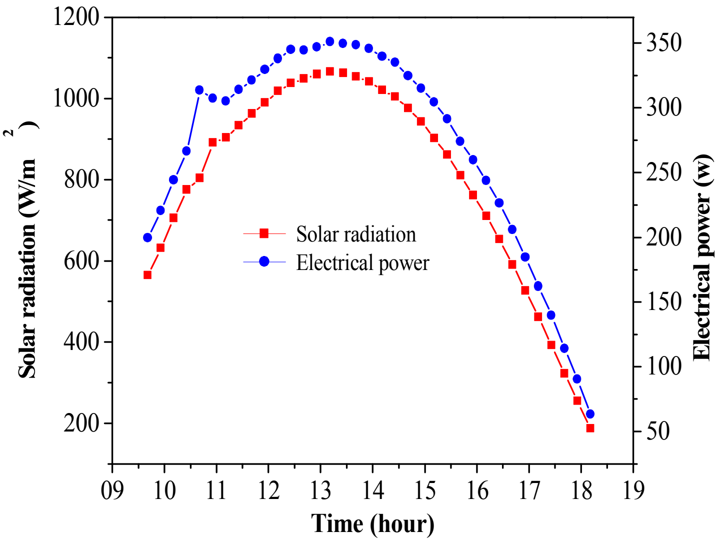

Fig. 4. Effect of solar irradiation on the electrical output of the Dualsun PV module.

Fig. 5 shows the effect of different levels of solar irradiation on the electrical efficiency of the Dualsun PV module. It is clear that the electrical efficiency decreases as the level of solar irradiation increases. This trend is particularly pronounced around solar midday, when the efficiency reaches its lowest point due to the maximum intensity of solar irradiation. At the beginning and end of the day, higher electrical efficiencies are observed. The increase in irradiation leads to a rise in the temperature of the PV cells, which in turn leads to a reduction in electrical efficiency. This is because solar cells operate less efficiently at higher temperatures. It is also interesting to note that the optimum electrical efficiency of the Dualsun PV module was recorded at 17h26, with a value of 18.96%. At this time of day, irradiance is low, which limits the temperature rise of the solar cells. As a result, the lower the temperature, the higher the efficiency, which explains the improved performance in the late afternoon.

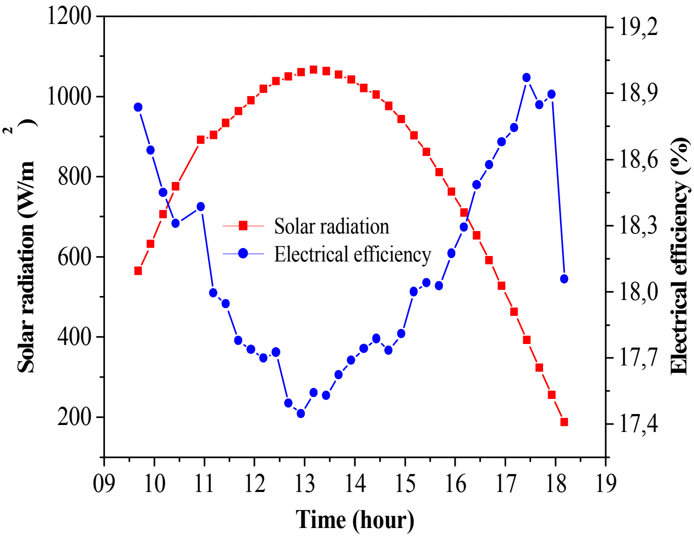

Fig. 5. Effect of solar irradiation on the electrical efficiency of the Dualsun PV module.

3.3 Impact of temperature on the electrical performance of PV modules

Fig. 6 shows actual thermal images of the PV modules studied, captured by an infrared camera, showing the temperature distribution. Lower temperatures are observed along the edges of the modules due to high convective heat exchange with the environment in three different directions. However, at the center of the PV module, higher temperatures are attributable to the low rate of convective heat transfer to the environment, which occurs in only two directions. Fig. 7 shows that as the temperature of the solar cells increases, the electrical efficiency of the PV module decreases. This is because as solar radiation increases, the module absorbs more energy, generating more heat. The accumulation of this heat raises the temperature of the solar cells, reducing their efficiency in converting light energy into electricity. As a result, the higher the cell temperature, the lower the electrical efficiency, particularly at times of high solar irradiation, such as around midday.

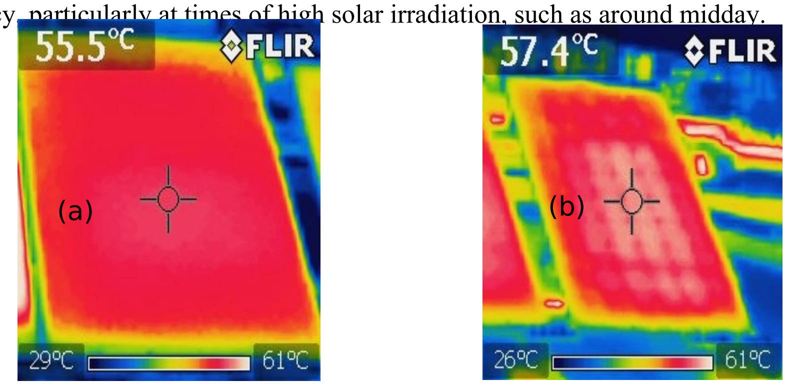

Fig. 6. Real-temperature images of PV modules (a: Dualsun; b: Almaden).

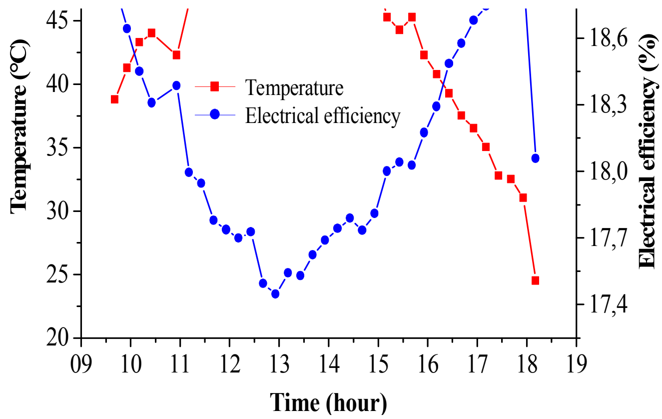

Fig. 7. Effect of temperature on the electrical efficiency of the Dualsun PV module.

3.4 Comparative performance analysis of two PV modules

Fig. 8 shows the temperature evolution of the front and rear surfaces of PV modules as a function of time. It can be seen that the temperature of the front surface of the PV modules is lower than that of the rear surface, attributable to the latter's proximity to the silicon layer. In addition, the temperatures of the Almaden module appear slightly higher than those of the Dualsun module, probably due to the double glass protection, which results in a greater glass thickness. In addition, the reduction in string currents for the Dualsun module thanks to smaller cells leads to lower ohmic losses, as solar cells for shingling are generally 1/6th of conventional cells. According to the study by Peter et al.[12], the findings indicate that solar modules with dual glass protection exhibit a slightly higher temperature due to the increased glass thickness.

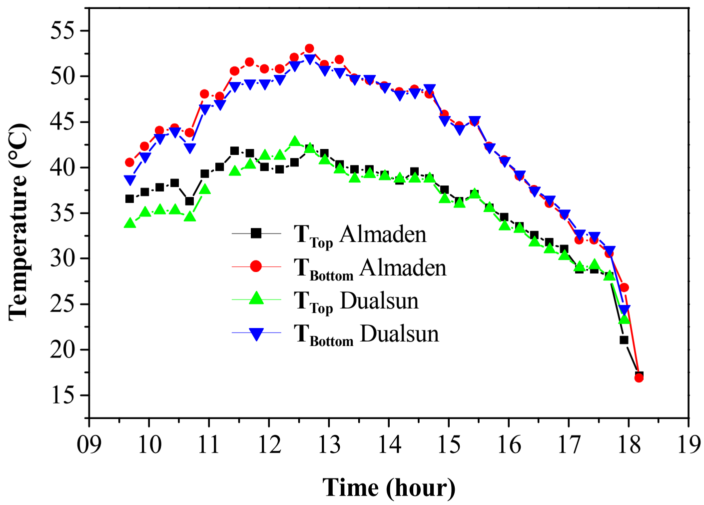

Fig. 8. Temperature evolution of the front and rear surfaces of PV modules.

Using the experimental data, a correlation between cell temperature and irradiance was established for both PV modules. Table 2 compares these two equations for an irradiance of

1000 W/m², highlighting that the Dualsun module maintains a lower temperature, enabling it to better withstand higher irradiance.

Table 2. Comparison of regression equations for the two PV modules

Type of PV	Regression Equation	Cell Temperature (°C) at 1000 W/m^2	Correlation coefficient (R^2)
Dualsun		38.43	0.9817
Almaden		39.14	0.9781

Fig. 9 shows the deviations of the PV modules' electrical efficiency from the manufacturer's values. It is clear that the maximum deviations were observed for the Almaden PV module, with a percentage deviation reaching 14.65%, while for the Dualsun module, the highest percentage deviation is 12.71%. These results suggest that the Dualsun PV module performs slightly better than the Almaden module.

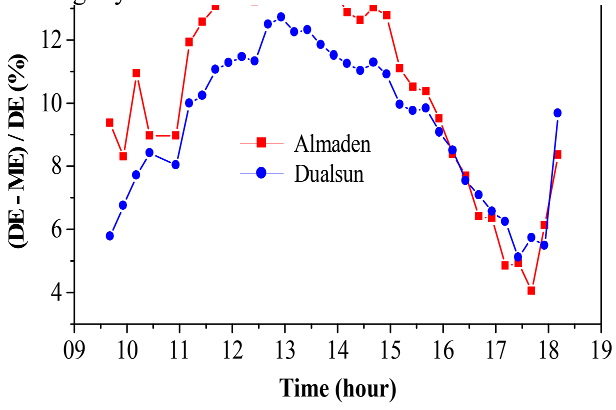

Fig. 9. Comparison of the efficiency of experimental PV modules with that of the manufacturer. (DE: Datasheet efficiency, ME: Measured efficiency).

The performance ratios of the PV modules studied are summarized in Table 3. The two PV modules showed almost identical performance ratios. The Dualsun module had an average performance ratio of 90.5%, while the Almaden module achieved an average ratio of 90%.

Table 3. PV module performance ratios

Performance ratios (PR) of modules PV	Dualsun (DSTI375G1-360SBB5)	Almaden (SEAC60T-300)
Maximum of PR (%)	94	95
Minimum of PR (%)	87	85
Average of PR (%)	90.5	90

4 Conclusion

In this study, we carried out performance analyses to compare two solar interconnection technologies, shingle and standard, under identical outdoor conditions. Here are the main conclusions:

- An increase in solar irradiance has a positive effect on electrical power, but it also increases the temperature of PV modules, which decreases their electrical efficiency.
- The temperature of Dualsun PV modules is slightly lower than that of Almaden PV modules, due to the advantages of shingle technology.
- The maximum deviations in electrical efficiency from the manufacturer's values were observed for the Almaden PV module, with a deviation of up to 14.65%, while for the Dualsun module the maximum deviation was 12.71%.
- The Dualsun module has an average performance ratio of 90.5%, while the Almaden module has an average ratio of 90%.

References

1. A.D. Kafui, I. Seres, I. Farkas, Efficiency Comparison of Different Photovoltaic Modules, Acta Technologica Agriculturae 22 (2019) 5–11. https://doi.org/10.2478/ata-2019-0002 .
2. Y. El Alami, A. Lamkaddem, H. Amiry, R. Bendaoud, F. Chanaa, S. Bounouar, S. Dlimi, K. Kassmi, E. Baghaz, R. Malek, S. Yadir, M. Benhmida, Design and realization of a descretized PV system with an improved MPPT control for a better exploitation of the PV energy, IJRER 14 (2024) 2. https://doi.org/10.20508/ijrer.v14i2.14354.g8884.
3. Y. El Alami, E. Chetouani, H. Mokhliss, F. Ouerradi, M. Aoutoul, S. Bounouar, R. Bendaoud, A. Faize, R. Rmaily, Optimizing solar energy efficiency with an improved hill-climbing maximum power point tracking control approach: hardware implementation, Clean Energy 8 (2024) 167–176. https://doi.org/10.1093/ce/zkae061 .
4. L. Theunissen, B. Willems, J. Burke, D. Tonini, M. Galiazzo, A. Henckens, Electrically conductive adhesives as cell interconnection material in shingled module technology, in: Lausanne, Switzerland, 2018: p. 080003. https://doi.org/10.1063/1.5049305 .
5. D. Tonini, G. Cellere, M. Bertazzo, A. Fecchio, L. Cerasti, M. Galiazzo, Shingling Technology For Cell Interconnection: Technological Aspects And Process Integration, Energy Procedia 150 (2018) 36–43. https://doi.org/10.1016/j.egypro.2018.09.010 .
6. Dualsun : Créateur français de solutions solaires, https://dualsun.com/ (accessed June 6, 2024).
7. High Power All-Black Solar Panels from Solaria | Solar Panels for Homes | Solar & Battery | Solar Panels — Solaria, https://www.solaria.com/solar-panels (accessed June 13, 2024).
8. Residential Solar, Energy Storage and EV Charging | SunPower, https://us.sunpower.com/ (accessed June 13, 2024).
9. C. Ma, R. Wu, Z. Liu, X. Li, Performance assessment of different photovoltaic module technologies in floating photovoltaic power plants under waters environment, Renewable Energy 222 (2024) 119890. https://doi.org/10.1016/j.renene.2023.119890.

10. Y.E. Alami, A. Lamkaddem, R. Bendaoud, S. Talbi, M. Louzazni, E. Baghaz, Numerical study of a water-based photovoltaic-thermal (PVT) hybrid solar collector with a new heat exchanger, E-Prime - Advances in Electrical Engineering, Electronics and Energy (2024) 100693. https://doi.org/10.1016/j.prime.2024.100693 .
11. Y. El Alami, B. Zohal, R. Nasrin, M. Benhmida, A. Faize, E. Baghaz, Solar thermal, photovoltaic, photovoltaic thermal, and photovoltaic thermal phase change material systems: A comprehensive reference guide, International Communications in Heat and Mass Transfer 159 (2024) 108135. https://doi.org/10.1016/j.icheatmasstransfer.2024.108135 .
12. N. Peter, O. E. Kabu, K. Stephen, D. Anthony, 3D finite element method modeling and simulation of the temperature of crystalline photovoltaic module, IJRET 04 (2015) 378–384. https://doi.org/10.15623/ijret.2015.0409070 .