Cooling System for Photovoltaic Panels

Maria Adelaide N. P. C. Ambrósio
Instituto Superior Técnico, Universidade de Lisboa
Lisbon, Portugal
adelaide.ambrosio@tecnico.ulisboa.pt

***Abstract*—With the increasing interest in the renewable energies, due to the rise in performances, the decrease in its prices and the increasing need for more sustainable solutions to power our societies, solar systems and especially photovoltaic systems have been an important asset. However, they present an almost counter-intuitive problem: in the peak hours of sun, their efficiency decreases due to the increase in temperature.In response to this problem, several systems have been designed using water, air and nanofluids as cooling agents. The main focus of this paper is studying floating systems and the consequent cooling effect.**

***Index Terms*—Photovoltaic systems, cooling systems, efficency**

I. Introduction

In the European Green Deal it is proposed by the European Commission to cut greenhouse gas emissions by at least 55% by 2030, which compels Europe to become climate neutral by 2050 - an economy with net-zero greenhouse gas emissions. In order to reach this goal more investment in Renewable Energy Sources must be made. Investment for their installation but also investment for their improvement. Solar energy is crucial in the development of a more environmental friendly future. Over the years the average selling price of solar modules decreased 20% for each doubling of production volume, which was enabled by market conditions as well as technological advancements. PV systems' prices have followed the lowering price tendency of the solar modules but at a slower pace. The technical components of these systems share a global market, which allows for their prices to be similar globally (not considering taxes and duties). The electric energy is produced through the photovoltaic effect, which converts the power transmitted in form of solar radiation to direct current using semiconductors. The photovoltaic effect is a physical phenomenon that occurs in the semiconductors when an adequate photon hits it, by the release of an electron-hole pair with the energy absorbed from the interaction. This effect is related to the conversion of radiative energy into electricity. The energy that is not converted to electrical energy is converted to thermal energy, which leads to the increase of temperature of the modules and consequently the reduction of their efficiency. This temperature increment leads to a decrease in the electrical output of around 0.4% to 0.65%, depending on the material, per every one degree increment in the operational temperature.

A. *Floating Technology*

Floating solar systems are a new way of implementing solar farms. Instead of the traditional rooftop or ground mounted systems, these are installed on large bodies of water such as the reservoirs of hydroelectric power plants, lakes and, under the right conditions, oceans. A report by Wood Mackenzie, a global research firm, argues that global floating solar demand is expected to grow by an average of 22 percent year-over-year from 2019 through 2024 [1].

Fig. 1. Floating System in Alto Rabagão dam reservoir, Montalegre, Portugal

An important benefit to floating technology is that no land is occupied. This land is valuable either for wild life, farming or construction. Reduced grid interconnection costs are also an advantage to these systems. Installing a new energy source where energy is already being injected into the network, called hybridization, allows for savings (due to the reduced infrastructure needed to be installed in order to achieve the goal of injecting this energy in the grid) and for the increase of the duration of the power supply.

Furthermore, these panels do not suffer from shading from buildings or other infrastructures near them, which allows for a better performance.

Another benefit, and the most relevant one for this dissertation, is the cooling effect that having these panels on a water surface brings. As seen previously, water is a very good cooling fluid due to its high specific heat capacity. Allowing the whole surface area of the panel to be in close contact with water can reduce the panel's temperature up to 5-10% [2] [3]. These values need further studying and investigation, given that this is a very recent technology, thus not much data is yet available nor many studies have been done on concrete cases and not only on hypothesis and simulations.

The environmental impact on the quality of water and on the wildlife are also prime concerns of this technology [4] and still lack deeper studying in order to understand the concrete implications.

B. CIGS

Copper indium gallium diselenide $CuIn_{(1-x)}Ga_xSe_2$ - CIGS - is a semicondutor that varies its band gap value between 1.0 - 1.7 eV depending on the proportion of its elements. It can originate thin film solar cells, which are composed by 6 (six) layers, from the top to the bottom, as can be seen in Figure 2.

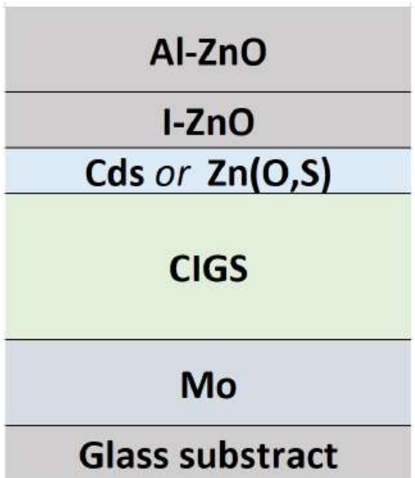

Fig. 2. CIGS cell model (levels not at scale).

CIGS are considered 2^{nd} generation technology. The 1^{st} one is based on crystalline silicon technologies, both monocrystalline and polycrystalline, and on gallium arsenide (GaAs); the 2^{nd} generation includes amorphous silicon (a-Si) and microcrystalline silicon (μ-Si) thin films solar cells, cadmium telluride/cadmium sulfide (CdTe/CdS) and copper indium gallium selenide (CIGS) solar cells; the 3^{rd} generation involves technologies based on more recent compounds such as nanocrystalline films, active quantum dots, tandem or stacked multilayers of inorganics based on III–V materials, such as GaAs/GaInP, organic (polymer)-based solar cells and dyed-sensitized solar cells; lastly, the 4^{th} generation combines the low cost and the flexibility of polymer thin films with the stability of novel inorganic nanostructures such as metal nanoparticles and metal oxides or organic-based nanomaterials like carbon nanotubes, graphene and its derivatives.

CIGS technology is expanding its presence in the solar panels market due to their low temperature coefficient and high absorption capability in the ultraviolet and infrared zones of the light spectrum. One way of inserting this technology into our societies is through BIPV (buildng integrated photovoltaic) systems. The thin film technology presents itself as the future of this technology due to the low weight, flexibility, suitability for vertical installation and affordability [5]. The vertical installation allows for curtain walls to be created, which increase the exposed area and decrease the visual pollution that some solar installations cause.

On the other hand, space technologies are a promising receptor of this technology. The low weight, specific volume and mechanical reliability are characteristics that make CIGS technlogy a good bet in space exploration [6].

C. Mono-Si

Monocrystalline silicon (Mono-Si) is the base material for silicon-based discrete components and integrated circuits used in virtually all modern electronic equipment. It can also be employed as a light-absorbing material in the production of solar cells, which is the application investigated in this research. As previously stated, silicon based technologies are first generation technologies and have the biggest market share in photovoltaic technologies.

Monocrystalline silicon cells present a higher production cost when compared to polycrystalline modules, but they also present higher efficiency. As a consequence, a smaller area of silicon is needed to produce the same amount of energy. This is the reason why they are primarily chosen for solar systems in rooftops, and for small systems that need power, such as traffic lights, velocity sensors, *etc*. They are also employed in big solar parks which aim at providing the general grid with energy, due to their high energy yield. For this latter option, new systems are being tested and employed, such as bifacial solar modules, which take advantage of the light reflection on the ground.

in 2020 Mono-si modules represented about 75% of the market share and it is predicted to keep growing [7] [8].

II. CIGS Experiments

A. CIGS Baseline

The specific panels used to perform the following experiments are from the brand Hanergy, the model is SC-8GUR and its technical specifications are as shown in Table I:

Power (W)	7.7
Output Voltage (V)	5
Peak Output Current (A)	1.2

TABLE I
SPECIFICATIONS.

They are similar to the ones in Figure 3:

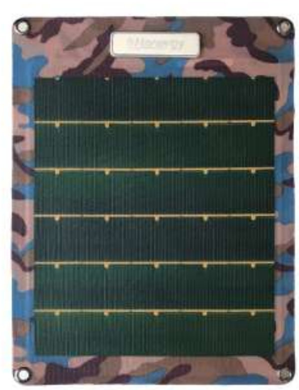

Fig. 3. CIGS panel used to perform the experiments.

Starting at room temperature, two I-V curves were obtained. The difference between them lies at the height at which the lamp was. The first experiment was performed at an height of 30 cm and the second one at an height of 15 cm. The lamp used was a 200 W incandescent Philips lamp and the area of the panel is 0.05184 m^2.

The I-V curves resulting of these experiments can be seen in Figure 4 and the corresponding P-V curves can be seen in Figure 5.

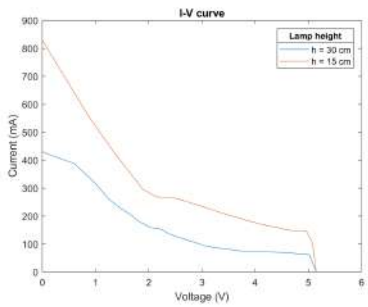

Fig. 4. I-V curves.

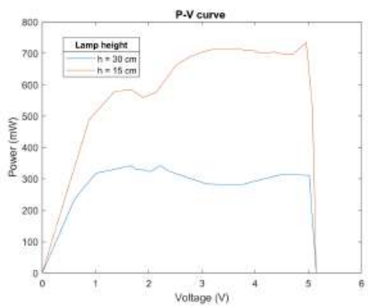

Fig. 5. P-V curves.

By lowering the lamp, the irradiance increases and consequently, so does the temperature of the panel. In the second experiment, which took around 10 minutes to perform and the lamp was constantly turned on, there was an increase of 6°C of the surface temperature of the module. It is expected that this temperature would keep increasing for as long as the experiment was running, *i.e.*, as long as the lamp was turned on. Although there was a temperature increase in the first experiment, it was not as significant as in the last one. However, given the short time it took to perform both these experiments, no alterations can be seen in the V_{OC} as would be expected.

B. CIGS - Floating in fresh water

Experiments were carried out to better understand the alterations that floating on water causes to the panels. In order to emulate the water of dam reservoir, a plastic box containing water was used. Since in real life conditions, the panels do not touch the water directly, two floats were employed, one on each end of the module, to prevent it from touching the water. The lamp in this experiment was placed at a distance of 15 cm from the solar module. The I-V (Figure 6) and P-V curves (Figure 7) were obtained, as well as the temperature of the module during the experiment. The water was at room temperature, and at this point there was no attempt of either cooling or heating it.

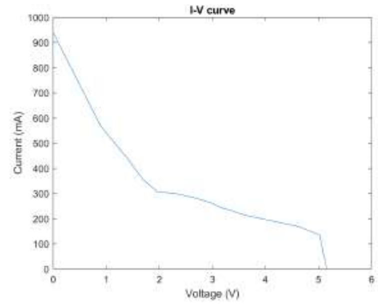

Fig. 6. I-V curve.

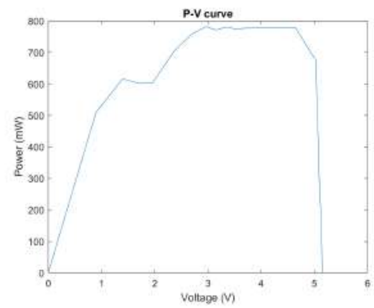

Fig. 7. P-V curve.

Comparing the findings of this experiment to those obtained for the same irradiance, that is, when the lamp was positioned 15 cm above the solar module, the I_{SC} increased approximately 100 mA, while the V_{OC} remained the same. Since both experiments took the same amount of time to perform, it can be inferred that floating modules are more efficient, as one would anticipate. For the 10 minutes it took to perform this experience, the temperature of the module rose 5 °C for the first 5 minutes and then it stabilised for the rest of the experiment. Extrapolating this information for real life conditions, it means that panels on floating conditions, will see their temperature increase just up to certain threshold, which will stabilise. This means that the panels will not reach a such high temperature that impair their functioning and efficiency, allowing for a bigger energy yield for the same amount of time as a system with the same specifications but mounted on the ground or in a rooftop.

C. CIGS - Floating in fresh water cooled by ice

In order to analyse the effect that the water temperature has on floating systems, in the same setup as used previously, 4 kg of ice were added to the water. The I-V and P-V curves were obtained for the following water temperatures:

- **8.5 °C**: the ice had been added a few minutes ago and it was still melting;
- **5.5 °C**: the ice had just finished melting, the water was at its coldest temperature;
- **6 °C**: the water was starting to increase its temperature.
- **7 °C**: the water was increasing its temperature.

It is expected that the colder the water, the higher the I_{SC}, as the temperature of the solar cells is not going to increase as to hinder the conversion efficiency.

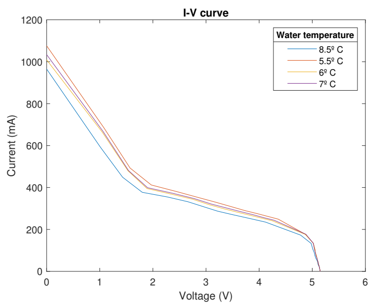

Fig. 8. I-V curves.

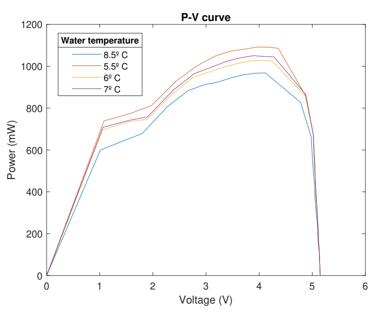

Fig. 9. P-V curves.

According to the previous graphs, the colder the water, the higher the value I_{SC}. Providing that the V_{OC} remains the same, the output power increases with the decrease of the water temperature, as was predicted. This means more energy extracted for the same amount of time which translates into better efficiency.

D. CIGS - Emulating waves in fresh water

Taking into account that under some very specific conditions floating parks can be installed in seas and not only lakes or reservoir dams, there was a need to study whether the movement of water had any effect on the performance of the solar modules.

The experimental setup is similar to the previous experiments: fresh water in a plastic box, the module set on floats at a distance of 15 cm from the lamp. In order to emulate waves, an electric mixer was used.

In this experiment there was only a 1,5 °C increase in the module's temperature. This can be explained due to the ambient temperature being low on this day when compared to

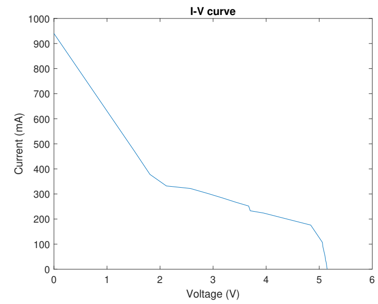

Fig. 10. I-V curve.

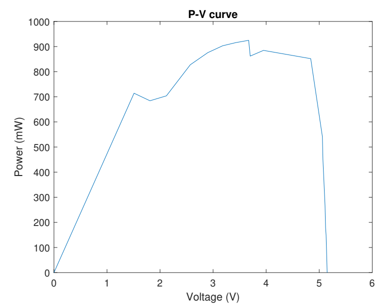

Fig. 11. P-V curve.

the previous experiments and due to the splashes of water that fall on the top of the module. Instead of the cooling being only done on the backside as in previous experiments, in this case cooling also happens on the front side, which prevents the temperature from rising as much. In the short run, this is a positive factor, however in the long run it It may have detrimental effects, as after the deposed water evaporates, foreign substances will be settled on the front of the panel, causing hotspots and in the longer run it may corrode and damage the front side of the panel altogether. This can be avoided with frequent cleaning and maintenance of the panel, although this brings extra costs which may exceed the value of the extra energy produced.

Due to the movement of the water and the constant rocking of the modules, which affects the angle at which light reaches the module and, as a result, its absorption and energy conversion, these curves are not as smooth as the prior ones.

E. CIGS - Emulating waves in fresh water cooled by ice

It was now necessary to evaluate the influence of the water temperature in the solar farms installed in the seas, where there is constant water movement. For this experiment, 4 kg of ice were added to the fresh water in the box as previously done and the waves were emulated with the electric mixer, as done in the last experiment.

The operating curves were obtained for the following water temperatures:

- **1.2 °C**: the ice had just finished melting, the water was at its coldest temperature;

- **5.5 °C**: the water temperature was increasing, this was similar value to one obtained previously, which allows for a good comparison.

The I-V and P-V curves can be observed in Figure 12 and Figure 13, respectively.

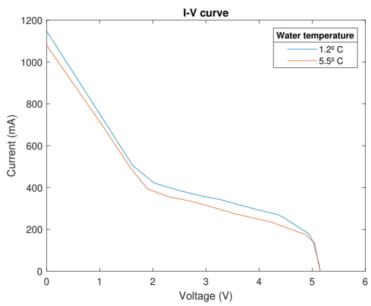

Fig. 12. I-V curves.

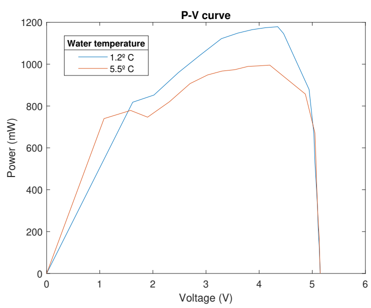

Fig. 13. P-V curves.

For the coldest water temperature registered, the solar module only increased its temperature in 0.5 °C. This is a very low value and it gets the module near its top performance. When the water reached 5.5 °C, there was an increase of 1 °C in the module's temperature. Comparing this value to the one obtained in Section II-C, in which there was an increase of 1.5 °C, it can be ascertained that the undulation has positive effects on the short term performance of the module.

III. Mono-Si Experiments

A. Mono-Si Baseline

In order to perform the experiments with another technology, two cells of Monocrystalline silicon were used. The cells in question are the Trina Solar TSM-DEG5-(II)-280 W and the technical Standard Testing Conditions specifications are in Table II

TABLE II
Mono-Si cells specifications.

Power (W)	4.6
Open Circuit Voltage (V_{OC})	4.25
Short Circuit Current (mA)	123

For the following experiments, two cells connected in series will be used, as shown in Figure 14:

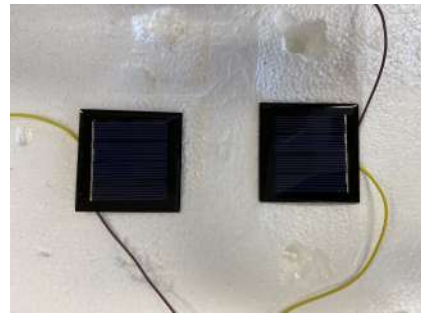

Fig. 14. Mono-Si cells used to perform the experiments.

Similarly to the previous technology, starting at room temperature, two I-V curves were obtained. The difference between them lies at the height of the lamp. The first experiment was performed at an height of 30 cm and the second one at the height of 15 cm.

The increase in radiation shows the increase in I_{SC}, which more than doubles when halving the height of the lamp. There is a small decrease in the value of V_{OC}, as would be expected due to the increase of the temperature of the module.

The resulting I-V of these experiments can be seen in Figure 15 and the corresponding P-V curves can be seen in Figure 16.

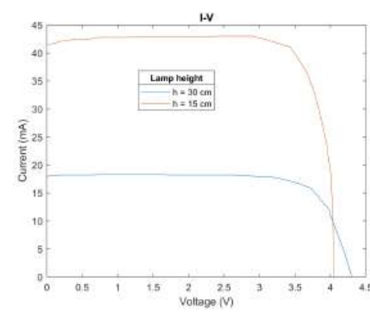

Fig. 15. I-V curves.

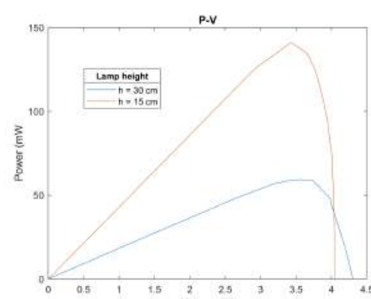

Fig. 16. P-V curves.

By lowering the lamp, not only is the irradiance increasing, but also the temperature of the panel is increasing. In the second experiment, which took around 10 minutes to perform and the lamp was constantly turned on, there was an increase of 22°C of the surface temperature of the module. Despite the short time it took to perform these experiments, the change in V_{OC} is significant.

Experiments were carried out to better understand the alterations that floating on water causes to the panels. In order to emulate a body of water, a plastic box containing tap water was used. While the CIGS modules could be in direct contact with water, monocrystalline silicon modules do not present any water resistance. In order to conduct these experiments, the modules were put inside a clear plastic bag. This may cause some small changes to the final results due to the reflection and refraction of the light on the plastic above the cells. As in earlier floating studies, the modules were made to float using floats. In this situation, there was an attempt to prevent placing the floats directly beneath the solar cell and instead tried placing them on the cell's periphery, where there is simply plastic and no photoelectric material.

The influence of the water temperature will be analysed and the results will be presented. It will also be studied if there is any difference between salted water, for panels installed in sea, and fresh water, for panels installed in lakes and dam reservoirs.

B. Mono-Si - Floating in fresh water

The lamp in this experiment was placed at a distance of 15 cm from the solar module. The I-V and P-V curves were obtained, as well as the temperature of the module during the experiment. The water was at room temperature, and at this point there was no attempt of either cooling or heating it.

In this experiment, it is expected that the I_{SC} will remain roughly the same, if not slightly higher, because of the light reflection on the water. The V_{OC} will not decrease since the module temperature will not increase as much compared to the previously established baseline.

The resulting I-V curve is presented in Figure 17 and the P-V curve is presented in Figure 18.

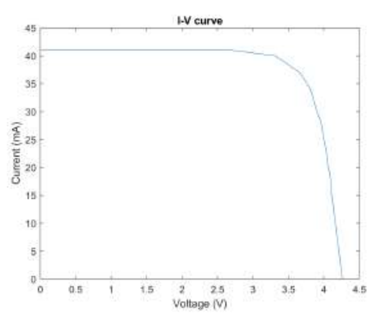

Fig. 17. I-V curve.

Comparing the findings of this experiment to those obtained for the same irradiance, that is, when the lamp was positioned 15 cm above the solar module, the I_{SC} remained approximately the same, while the V_{OC} increased 0.2 V. Since both experiments took the same amount of time to perform, it can be inferred that floating modules are sightly more efficient, as one would anticipate.

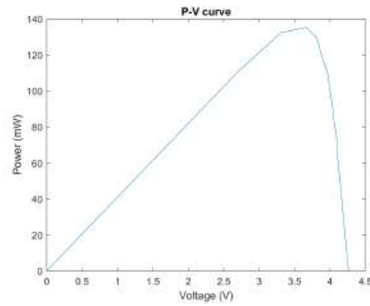

Fig. 18. P-V curve.

The temperature of the cells rose 20 °C in the 10 minutes it took to perform the experiment, which is 2 °C less than that observed in the baseline.

C. Mono-Si - Floating in fresh water cooled by ice

In order to analyse the effect that the water temperature has on floating systems, in the same setup as used previously, 4 kg of ice were added to the water. The I-V and P-V curves were obtained for the following water temperatures:

- **8.5 °C**: the ice had been added a few minutes ago and it was still melting;
- **6 °C**: the ice had just finished melting, the water was at its coldest temperature;
- **7 °C**: the water was starting to increase its temperature.
- **12 °C**: the water was increasing its temperature.

It is expected that the colder the water, the higher the I_{SC}, as the temperature of the solar cells is not going to increase as to hinder the conversion efficiency. It is also expected that beyond a certain water temperature, the efficiency of the cells will be approximate to their efficiency with the water at room temperature, as the increase of the cells' temperature will be enough to impair the efficiency.

The results of the experiment are shown in the following Figure 19 and Figure 20.

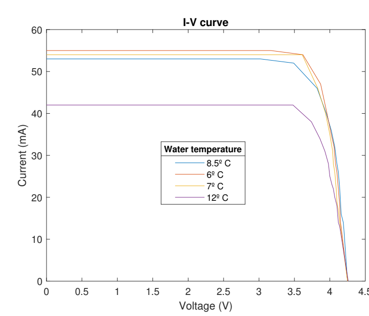

Fig. 19. I-V curves.

As can be seen in Figure 19, the colder the water, the higher the short circuit current as expected. There is no significant change in the value of the open circuit voltage.

There is a significant drop in the value of the current when the water temperature reaches 12 °C and the I_{SC} reaches the

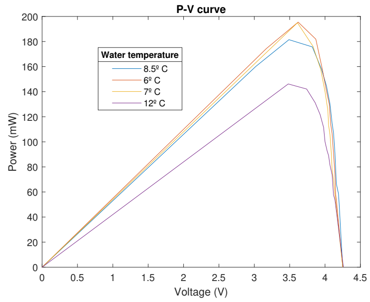

Fig. 20. P-V curves.

same value as it did in the experiment performed with water at room temperature.

The water temperature is the key in improving the efficiency of the floating panels. This could mean that this technology could prove to be very efficient in colder climate countries.

D. Mono-Si - Emulating waves in fresh water

Taking into account that under some very specific conditions floating parks can be installed in seas and not only lakes or reservoir dams, there was a need to study whether the movement of water had any effect on the performance of the solar modules.

The experimental setup is similar to the previous experiments: fresh water in a plastic box, the module set on floats at a distance of 15 cm from the lamp and the silicon modules inside a clear plastic bag. In order to emulate waves, an electric mixer was used.

The results obtained in this experiment can be seen in Figure 21 and Figure 22.

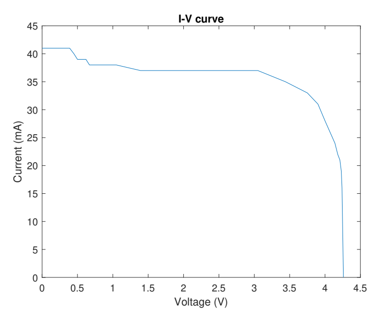

Fig. 21. I-V curve.

As seen with the CIGS modules, the curves obtained are not as clean as the ones obtained for the other experiments, due to the movement of the water and the constant rocking of the modules, which affects the angle at which light reaches the module and, as a result, its absorption and energy conversion

In this experiment there was a 13 °C increase in the module's temperature. Similarly to what happened with the CIGS module, this result can be explained due to the ambient temperature being low on this day when compared to the previous experiments and due to the splashes of water that fall on the top of the module. Instead of the cooling being

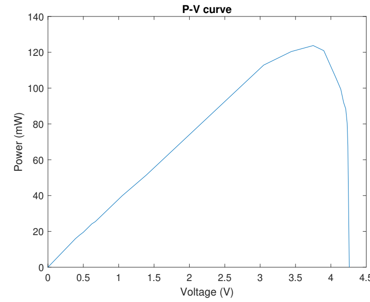

Fig. 22. P-V curve.

only done on the backside as in previous experiments, in this case cooling also happens on the front side, which prevents the temperature from rising as much. In the short run, this is a positive factor, however in the long run it It may have detrimental effects, as after the deposed water evaporates, foreign substances will be settled on the front of the panel, causing hotspots and in the longer run it may corrode and damage the front side of the panel altogether. This water deposition on the front side of the panel is more harmful in the case of silicon modules since they are not water resistant and are more susceptible to damages and corrosion. The negative effects can be avoided with frequent cleaning and maintenance of the panel, tough it brings extra costs which may exceed the value of the extra energy produced.

E. Mono-Si - Emulating waves in fresh water cooled by ice

In order to evaluate the influence of the water temperature in the solar farms installed in the seas using monocrystalline silicon, an experiment was set up, where 4 kg of ice were added to the fresh water in the box as previously done and the waves were emulated with the electric mixer, as done in the last experiment.

The operating curves were obtained for the following water temperatures, which had been tested in Section III-C:

- **6 °C**: the ice had just finished melting, the water was at its coldest temperature;
- **7 °C**: the water temperature was increasing, this was similar value to one obtained previously, which allows for a good comparison.

The I-V and P-V curves can be observed in Figure 23 and Figure 24, respectively.

When the water was at 6 °C, under these conditions, there was an increase in the module's temperature of 11.5 °C, which is 1.5 °C less than in Section III-C. There was no difference in the temperature of the module when the water was 7 °C. This smaller change in the module's temperature can be attributed to the silicon's higher temperature coefficient, when compared to that of the CIGS modules.

IV. Conclusions

The choice of studying floating systems deeper stems from the fact that these systems have been proved to be more efficiently and are the most effective for bigger solar parks,

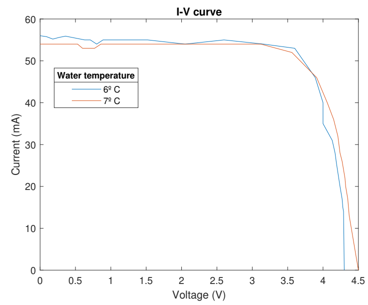

Fig. 23. I-V curves.

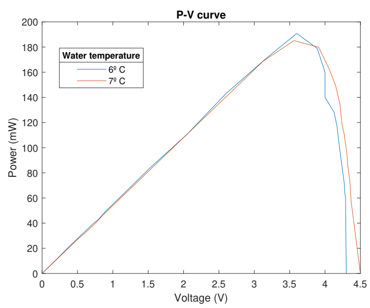

Fig. 24. P-V curves.

whereas systems with either water or air circulation cannot be scaled for big parks and remain efficient. This is the most realistic approach for "real life" systems and one that is predicted to continue being explored in years to come.

At first a baseline for both CIGS and Monocrystalline Silicon was established in order to establish comparisons with the following experiments and to allow for a conclusion to be drawn on whether or not there was an improvement with the experiments that were being performed. The temperature of the cells at the beginning and at the end of the experiment was registered. Later on, both solar modules were made to float on fresh water, which was at room temperature and their current-voltage curves were extracted. Both the water temperature and the cells temperature was registered. Comparing the temperatures of both solar modules, it was evident that the temperature had not risen as much as in the first experiment, and it was also noted that after a while the temperature stopped increasing at all, remaining stable for half of the time that took to complete the measurements. The following experiment for the evaluation of the influence that the water temperature has on solar modules. As was expected, the colder the water, the less the temperature increased, which meant higher short circuit current and, consequently, higher power and energy yield. With the Mono-Si modules it could also be seen that after a certain point, there was no influence of the water temperature, as the increase of the module temperature is very close whether the water had been cooled or not. Since under some conditions floating systems can be installed in oceans, there was also the need of studying whether the moving water had any extra effect on the temperature of the modules. When the water was at room temperature, it provided a considerable cooling effect, since there was water deposition on the front of the modules and running water on the back. The water on the front can pose some problems, as previously explained, but it helps with keeping the temperature down. Afterwards, it was investigated the influence of the moving colder water, and as anticipated, the colder water proved to be more efficient at keeping the modules colder and providing more power. Nevertheless, they present the same problem with the deposition of water on the front. It can be tackled with a cleaning team that goes to the location occasionally. This will, however, bring extra costs.

It can be concluded that floating systems are, overall, an improvement to the typically ground-mounted systems. They are a good investment, particularly in colder climate countries, as the water will be at a lower temperature, allowing for a smaller and less affecting temperature rise of the modules.

Tables summarising the experiments and their findings are shown next (see Table III for results of the CIGS modules and Table IV for results of monocrystalline silicon modules).

TABLE III
SUMMARY OF TEMPERATURE INCREASES FOR CIGS TECHNOLOGY.

Situation	Water Temp. [°C]	Temp. Increase [°C]
Baseline	-	10
Floating in fresh water	20	5
Floating in fresh water cooled by ice	8 5.5 6 7	3.5 1.5 2.5 3
Emulating waves in fresh water	13	1.5
Emulating waves in fresh water cooled by ice	1.2 5.5	0.5 1

TABLE IV
SUMMARY OF TEMPERATURE INCREASES FOR MONO-SI TECHNOLOGY.

Situation	Water Temp. [°C]	Temp. Increase [°C]
Baseline	-	22
Floating in fresh water	20	20
Floating in fresh water cooled by ice	8.5 6 7 12	14 13 13.5 16
Emulating waves in fresh water	13	13
Emulating waves in fresh water cooled by ice	6 7	11.5 14

REFERENCES

[1] W. Mackenzie,"Floating solar landscape 2019 = Available at https://www.woodmac.com/our-expertise/focus/Power-Renewables/floating-solar-2019/?utmsource=gtmarticle&utmmedium=web&utmcampaign=wmprfloatingsolar" (2019/09/19).

[2] I. F. C. W. B. Group, "Floating solar photovoltaic on the rise = Available at https://www.ifc.org/wps/wcm/connect/6ef92aa8-bf29-4c43-8edc-a0f7555e6a5d/IFC-EnergyNotes-FloatingSolarWEB.pdf?MOD=AJPERES&CVID=n8KDCtS (2020/05)."

[3] Pietro Elia Campana, Louise Wasthagea, Worrada Nookueaa, Yuting Tanb, Jinyue Yan, "Optimization and assessment of floating and floating-tracking pv systems integrated in on- and off-grid hybrid energy systems," Solar Energy, no. 117, pp. 782–795, 2019

[4] Alok Sahu, Neha Yadav, K. Sudhakar, “Floating photovoltaic power plant: A review”, Renewable and Sustainable Energy Reviews, vol. 66, pp. 815–824, 2016

[5] B. P. Jelle, C. Breivik, “The path to the building integrated photovoltaics of tomorrow”,Energy Procedia, vol. 20, pp. 78–87, 2012.

[6] Samar Dabbabi, Tarek Ben Nasr, Najoua Turki Kamoun , “Cigs solar cells for space applications: Numerical simulation of the effect of traps created by high-energy electron and proton irradiation on the performance of solar cells”, The Journal of The Minerals, Metals & Materials Society (TMS),no. 71, p. 602–607, February 2018.

[7] S. B. Hub, “Monocrystalline silicon wafers market share expected to reach nearly 75 percent in 2020and continue to grow, itrpv report finds = Available at https://solarbusinesshub.com/2020/05/08/monocrystalline-silicon-wafers-market-share-expected-to-reach-nearly-75-percent-in-2020-and-continue-to-grow-itrpv-report-finds/.”

[8] . B. M. Research, “Global monocrystalline solar cell (mono-si) market – industrytrends and forecast to 2027 = Available at https://www.databridgemarketresearch.com/reports/global-monocrystalline-solar-cell-mono-si-market.”