

THESIS WORK

Master of Science in Energy and Environment

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DEVELOPMENT OF A PV SOLAR SYSTEM TO POWER AN EXISTING PROTOTYPE OF SODIUM CHLORIDE ELECTROLYSER

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Abstract

Die vorliegende Masterarbeit entwickelt eine Photovoltaikanlage zur Energieversorgung eines schon existierenden Prototyps eines Natriumchlorid Elektrolyseurs. Hierzu wurden zuerst die für die Dimensionierung nötigen Charakteristiken des Elektrolyseurs gemessen. Als Randbedingung für die Dauer des Prozesses wurden zwei durchschnittlich strahlungsintensive Tage angenommen. Mit dieser Information wurde eine Strahlungsanalyse an verschiedenen Standorten vorgenommen um die benötigte installierte Leistung zu ermitteln. Anschließend wurden fünf verschiedene Konzepte entwickelt um Elektrolyseur und Photovoltaikpaneele zu verbinden. Die entwickelten Konzepte wurden dann anhand technischer und ökonomischer Kriterien bewertet und das beste Konzept ausgewählt. Die Arbeit soll eine Leitfaden geben für zukünftige ähnliche Projekte.

Extracto

Esta tesis de maestría desarrolla un sistema fotovoltaico para alimentar un prototipo existente de electrolizador de cloruro de sodio, cuyo subproducto podría utilizarse para potabilizar agua. A efectos de dimensionar los paneles fotovoltaicos, se relevaron las características del electrolizador, se midieron parámetros de interés y se fijó para el proceso una duración de dos días, con la radiación solar promedio en Buenos Aires. Se consideró luego la radiación solar media en sitios con necesidad de agua potable, a fin de estimar la potencia eléctrica requerida en cada caso. Para conectar los paneles fotovoltaicos al electrolizador, se desarrollaron cinco conceptos diferentes. Estos fueron evaluados según criterios técnicos y económicos a fin de elegir el mejor. El trabajo realizado pretende ser una guía para futuros proyectos similares.

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1 Introduction

In 2015, 768 million people had no access to clean drinking water according to Caritas International. Such a report triggered the idea of building a simple solar powered electrolyzer of aqueous sodium chloride solution, which products could in turn be used for water cleansing. [1]

The idea of using photovoltaic panels (PV panels) as power source was derived from the difficulty or even impossibility of connection to an electrical power grid which exists in most regions with polluted drinking water sources. With one liter of aqueous solution with a chlorine concentration of 10 g/l, 10.000 liters of water may be cleaned. The existing prototype of the sodium chloride solution electrolyzer had a capacity of 30 liters, therefore enough for treating up to 300.000 liters of water. With an initial concentration of 30 grams of sodium chloride per liter of water, and after a process time of 24 hours at 19 A (456Ah), the sufficient concentration of chlorine could be attained.

The task of this work was therefore to find a fitting installation to power the existing electrolyzer prototype with PV panels. One of the important questions regarded was whether it was possible to gather the required 456Ah (approximately 3200 Wh) in one day. Other aspects which were taken into consideration were the most appropriate set up including costs, installation simplicity, and easiness of handling.

Consequently, it was necessary to study the characteristics of the electrolyzer and also make a solar radiation analysis. Next, different connection possibilities were developed and the most fitting solution was finally selected, constructed and validated.

2 Sodium chloride electrolyser

2.1 System arrangement

The electrolyser used in this study consisted of a plastic container with enough volume capacity to carry the desired 30 liters of solution, inside which the electrodes were placed as to always remain submerged during the process. The anode used was recovered in titanium, placed in between two titanium cathodes.



Figure 1: Complete electrolyser, plastic container with electrodes inside

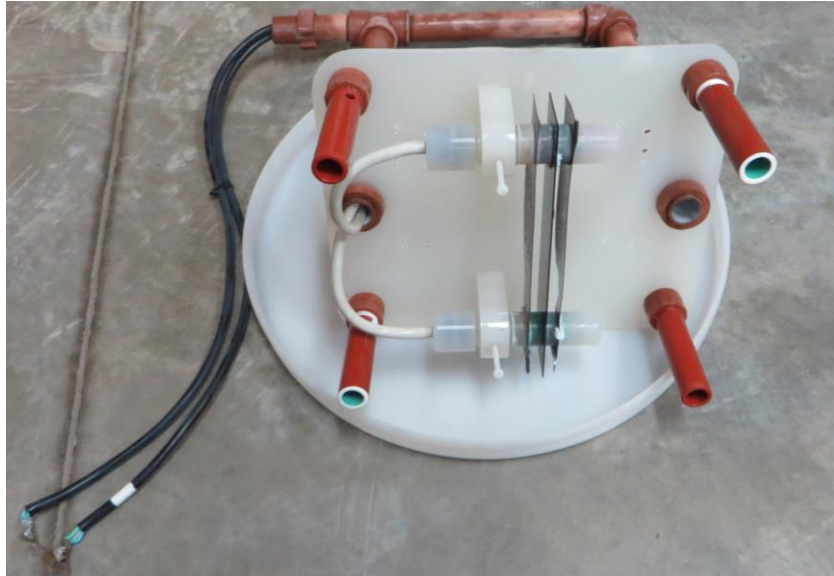


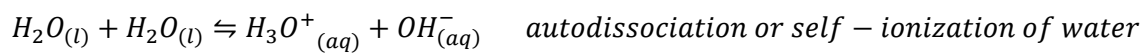
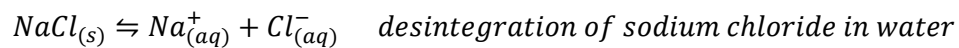
Figure 2: Electrodes together with their mounting structure and the connecting cables

The aqueous solution of sodium chloride used as electrolyte was obtained by dissolving 900 grams of industrial salt in 30 liters of tap water, obtaining the desired initial concentration of 30 g/l.

In order to test the electrolyser's performance, the electrodes were directly connected to a DC current source, set to constantly provided 19 A.

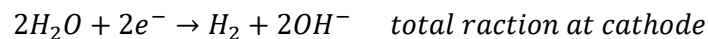
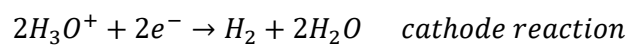
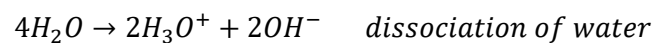
2.2 Chemical reactions

Before starting the electrolysis process, there are two-way reactions which take place when dissolving sodium chloride in water. Such reactions are the disintegration of the sodium chloride framework into Na^+ and Cl^- ions, and the auto dissociation of water into hydroxide and hydronium ions [2]:

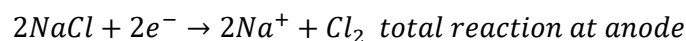
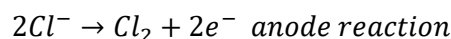


During the electrolysis process, the triggered reactions may be separated as those which take place at the cathodes and those which take place at the anode:

Cathode reaction [2]:

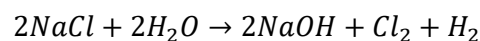


Anode reaction [2]:



Thus, the whole sodium chloride electrolysis produces sodium hydroxide, chlorine and hydrogen.

Total reaction [2]:



2.3 Current-voltage characteristics

Since the electrolyzer used in this project was a prototype it was necessary to measure the current-voltage characteristics. These I-V curves were later on used both to develop different alternatives to connect the electrolyzer with the PV panels, and to determine the characteristics such panels should have.

The characteristic curves of the electrolyzer were determined for 4 different situations, shown in **Figure 3**: before the electrolyzing process, at room temperature (20 °C) and at working temperature (approx. 42 °C), and after 24 hours of electrolysis (when the final desired concentration of dissolved chlorine in water is reached), both at the same temperatures. Using a direct current electrical supply and starting from 0 A, per every one more Ampere of current, the values of voltage were registered. The current was hence elevated in steps of 1 Ampere until the maximum current of the used power supply, of approximately 20 Ampere.

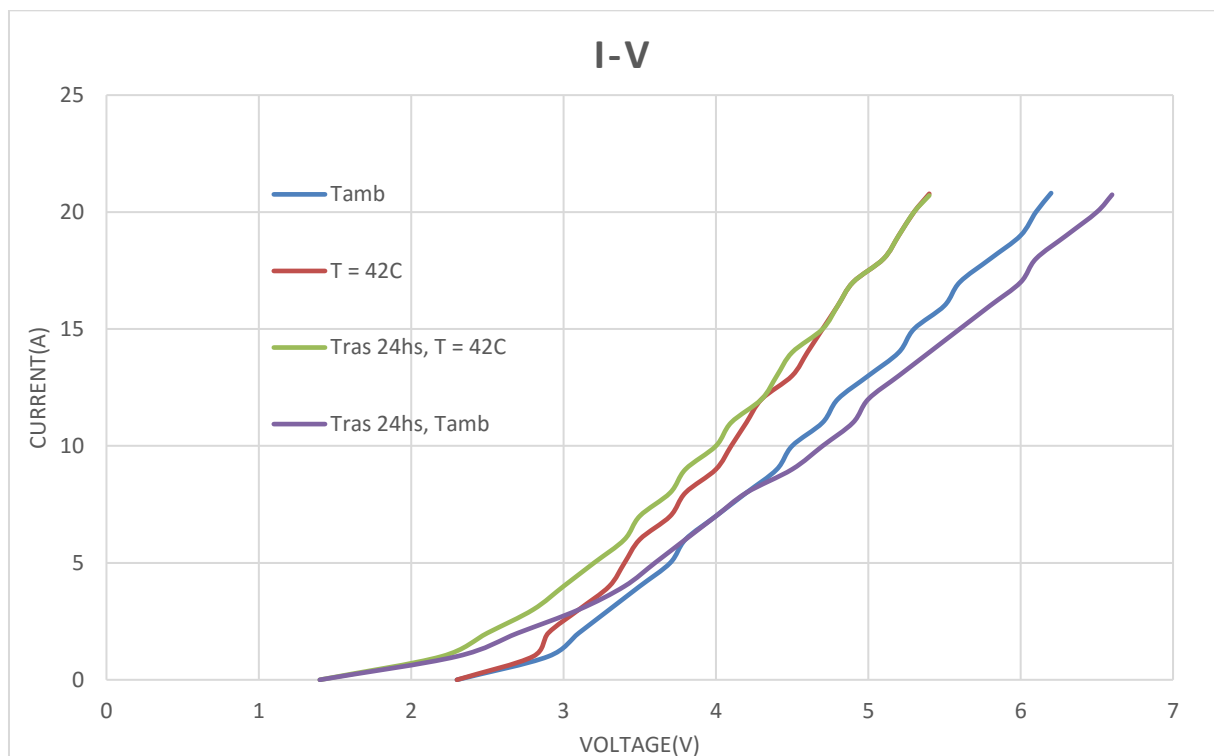


Figure 3: Current-voltage characteristics

The results show that after 24 hours the minimum voltage is lower than the minimum voltage registered before the electrolysis was started. Furthermore, the gradient of the characteristic

is higher at working temperature than at room temperature. Another observation is that at working temperature, the characteristics before and after the process meet at 20 Ampere, while at room temperature they meet earlier at 7 Ampere. What is more, at room temperature the maximum voltage measured after the process exceeds the maximum voltage measured before the process.

This data was used to calculate a general machine characteristic. The four measured characteristics first were linearly approximated. Afterwards an average characteristic was calculated out of the four linear approximations. **Figure 4** shows the results of the linear approximation.

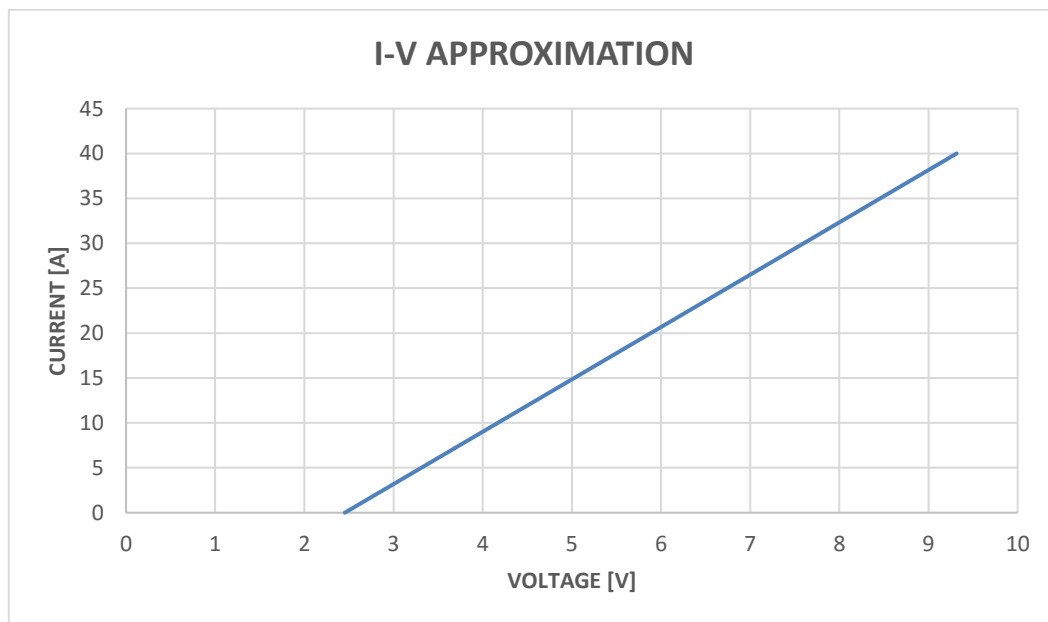


Figure 4: Linear Approximation of the machine characteristic

2.4 Chlorine concentration curve

In order to know the duration and the total charge needed for the process to be completed, it was necessary to measure the concentration of the electrolyte solution throughout the process. From former experiments, it was already known that with a current of 19 Ampere the electrolyzer could produce the desired chlorine concentration of approximately 10 grams per liter. Such experiments had been made with an initial concentration of 30 grams of sodium chloride per liter of water. Therefore, it was decided to carry out the process using the same initial electrolyte concentration and constant value of current.

Using the same power supply as in the measurements done for the current-voltage characteristics, the electrolysis was thus put to start, providing a constant current of 19A all throughout. Starting with a concentration of 0 grams of chlorine per liter, every one hour a sample was taken from the electrolyte solution in the container. In order to avoid measurement errors due to chlorine decay, the experiment was made all at once, 24 hours nonstop. Consequently, as shown in **Figure 5**, no samples could be measured for chlorine concentration in between hour 5 and 20 because of the limitation to office hours.

The samples were analyzed with a Free Chlorine Checker® HC - HI701 from Hanna Instruments, which range was limited to 3,5 ppm. Therefore, the samples had to be diluted with tap water. In order to avoid miscalculations, the chlorine concentration of the tap water had to be registered and taken into consideration.

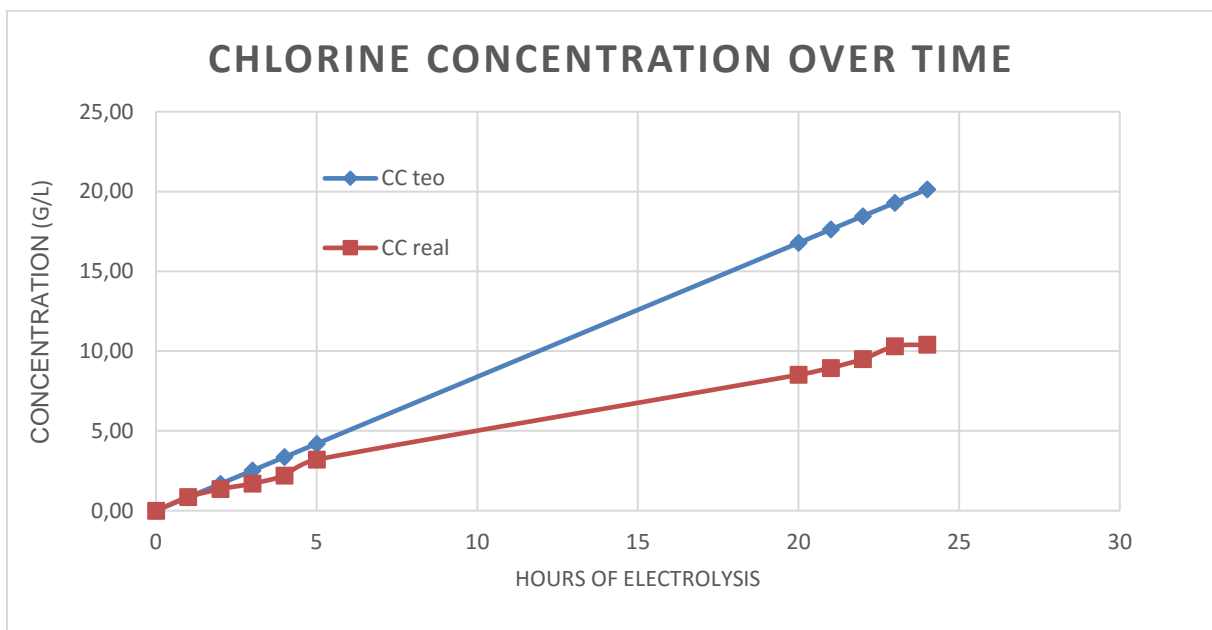


Figure 5: Theoretical and real chlorine concentrations at different process times

From the reactions mentioned in part 2.2, the theoretical chlorine concentration to be obtained for each point in time could be calculated. Therefore an efficiency of 100% was assumed. Such values were in turn compared with the real chlorine concentration obtained during the process,

making it possible to determine process efficiency. As revealed by **Figure 5**, real process concentrations are clearly lower than the theoretical values. Nevertheless, the real process also shows a linear trend. The calculated efficiency after 24 hours was 51,65%, meaning that approximately only half of the produced chlorine remains in the aqueous solution in the container. The rest of the chlorine produced during the electrolysis is in the form of Cl_2 -gas, and is free to escape.

The results obtained also reveal that the desired chlorine concentration of 10 g/l was reached in between the 22nd and 23rd hour of process.

Figure 6 shows the evolution of voltage with process time. During the first hours of processing there is a fast drop in voltage, but after the fourth hour of process, a slowly decaying linear trend can be observed. Calculating the area under this curve gives the Volts-hs required for the whole process which, multiplied by the 19A of constant current, give the total energy that has to be supplied to obtain the desired chlorine concentration. An approximation to this value gives:

$$19A \cdot 24hs \cdot 7V \approx 3200Wh \quad \text{energy needed}$$

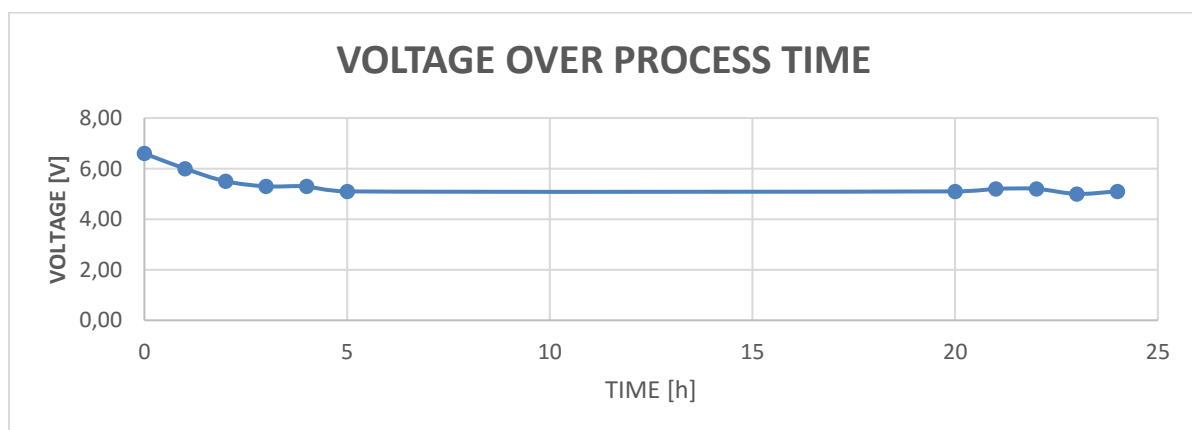


Figure 6: Voltage over process time

2.5 Decay of chlorine concentration

Since the total process at 20 A takes 24 hours and there is only 12 hours of sun a day it was important to know the behavior of the solution after the process. With this information was decided whether the process can take several days or not. Therefore the decay of the chlorine concentration in the container after the process was measured. Several samples were taken at different moments after the process. The chlorine concentration was determined for each sample and plotted over the time (see **Figure 7**). It can be seen that there is a significant decay in the chlorine concentration. After one week only half of the chlorine still is in the solution. Out of this reason it was decided to limit the days in which the process had to be done. It was decided that the process should be completed after maximum three days. This information was really important for the dimensioning of the panel size.

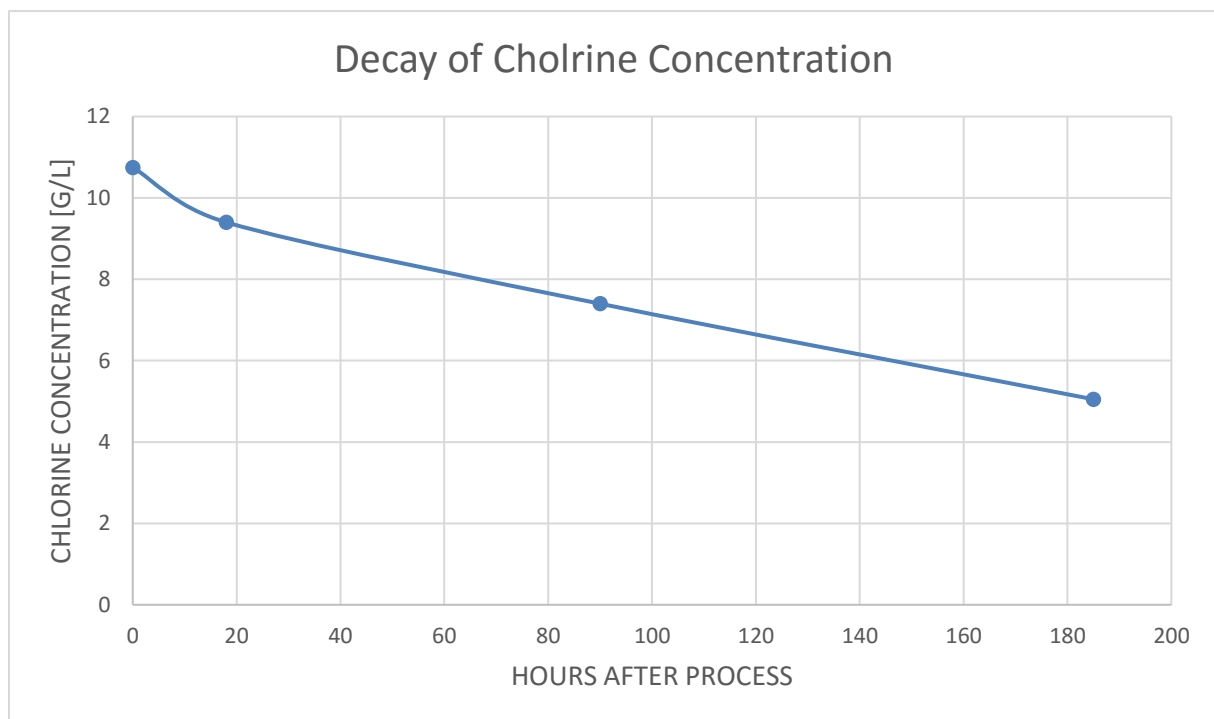


Figure 7: Decay of chlorine concentration over time

3 Radiation analysis

Three different locations were studied for solar radiation. The first location considered was the city of Buenos Aires, where the project was realized and therefore the simulated weather data could be validated the easiest. The other two locations were selected based on possible application places. China and India are the countries where the highest numbers of people with no access to clean drinking water are registered. Consequently, the other two cities to be considered were Nagpur, in India, and Madoi Huangheyan, in central China.

The condition set on the performance of the electrolyzer was that it should be possible to complete the electrolysis process in two consecutive average irradiance days (autumn or spring), or in three consecutive days with the lowest irradiance per day for that location (winter). The reason for such constraint was to limit the panel size needed. Therefore, an aim to this study was to determine the required panel size to generate the 456 Ampere-hours. Behavior of the photovoltaic system could be simulated using the software System Advisor Model (SAM), which already includes weather and panel data. For all analysis a panel with the operating voltage of 8 Volt was used. Using this panels the smallest amount of installed power is needed, because the maximum power point (MPP) of these panels is the closest to the operation point of the electrolyser. Differences in installed power due to different operation points were considered in chapter 4 [3].

3.1 Buenos Aires

Being located on the southern hemisphere, the panels in Buenos Aires had to be oriented to the north and thus, the azimuth angel of the panels was set to 0° . The tilt angel was fixed to 30° , and two consecutive days in March were selected as sunny average days to carry out the simulation. With such specifications, it was proven that with a panel of 360 W the required 456 Ampere-hours could be generated. **Figure 8** shows the solar irradiance and generated current during the two selected days. Ultimately, making an approximate integration, it was calculated that such panels could give 460 Ampere-hours.

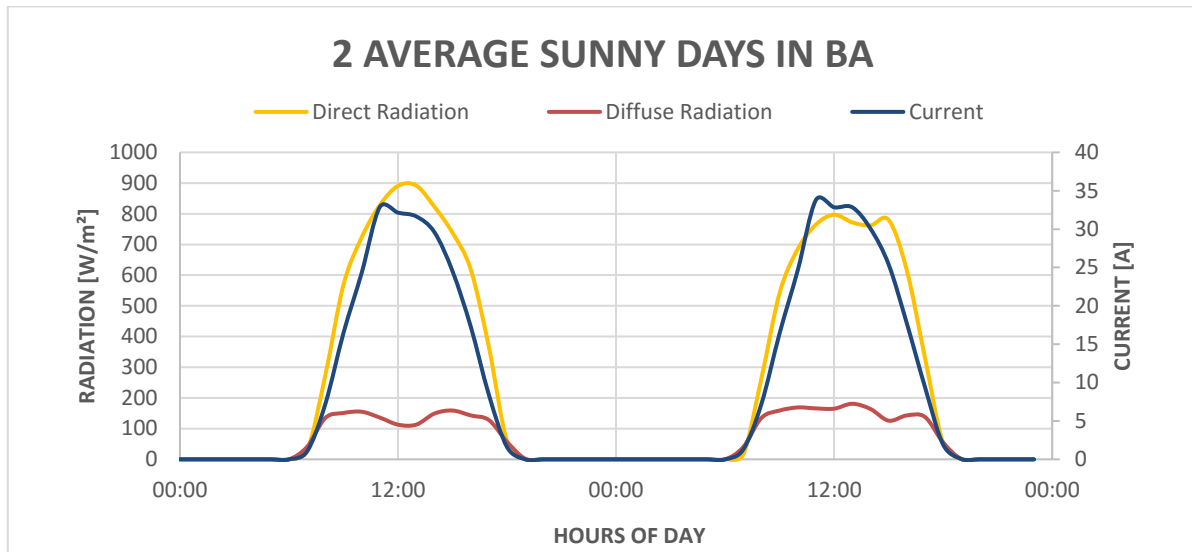


Figure 8: Irradiance and generated current for two consecutive average sunny days in Buenos Aires [3]

The simulation was repeated for other 3 consecutive days in July (winter), representing the worst irradiance scenario. It had to be possible to produce the same amount of Ampere-hours. Effectively, after running the simulation, it was calculated that 460 Ampere-hours could be generated under such circumstances. **Figure 9** shows the solar irradiance and generated current during the three selected days.

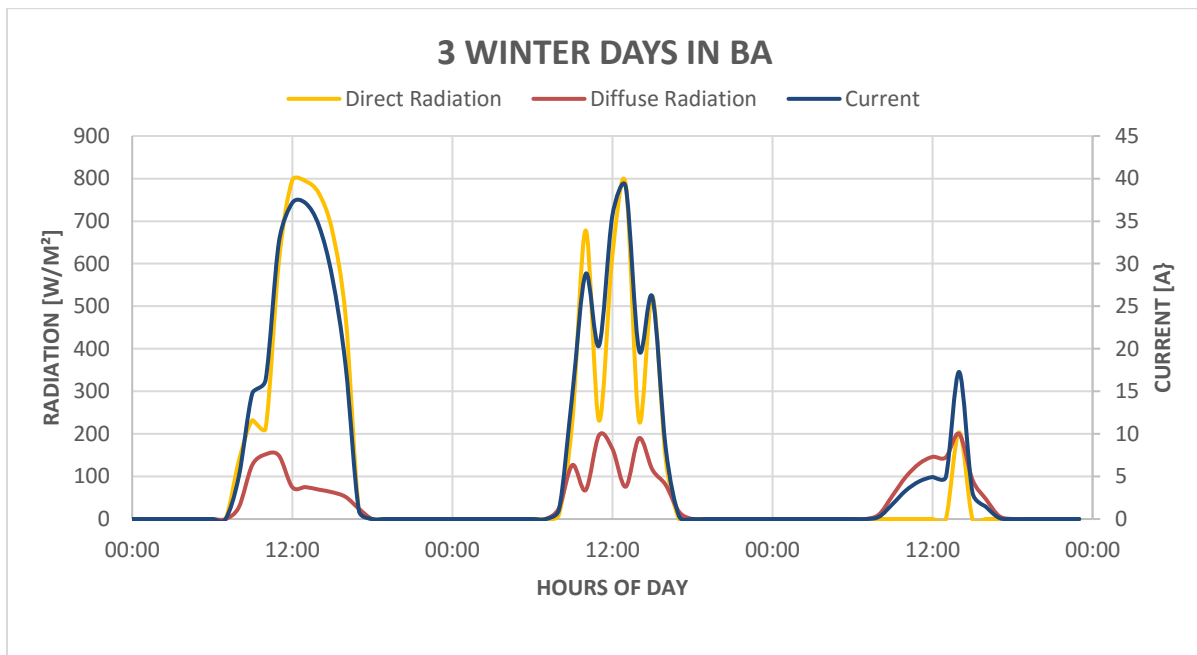


Figure 9: Irradiance and generated current for three winter days in Buenos Aires [3]

Another interesting aspect is that, if instead of having a fixed tilt angle, the tilt is monthly adjusted, a higher amount of Ampere-hours can be generated. This applies especially in the winter season. **Figure 10** shows the optimal tilt angles corresponding to each month.

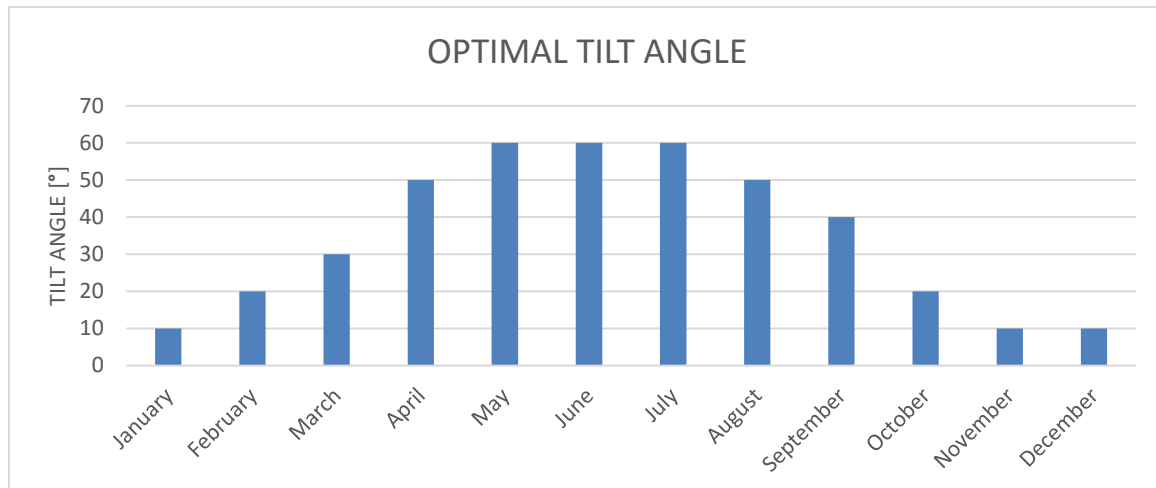


Figure 10: Monthly optimal tilt angle for Buenos Aires [3]

3.2 Nagpur (India)

The same simulations as for Buenos Aires were run for Nagpur in India. Nagpur is located in the center of India and is still on the northern hemisphere. Therefore, the azimuth angle was set to 180° , which means panel orientation to the south. The tilt angle was also fixed to 30° . The results obtained for two average days (shown in Figure 117) revealed that 502 Ampere-hours could be generated using 420 W of panels.

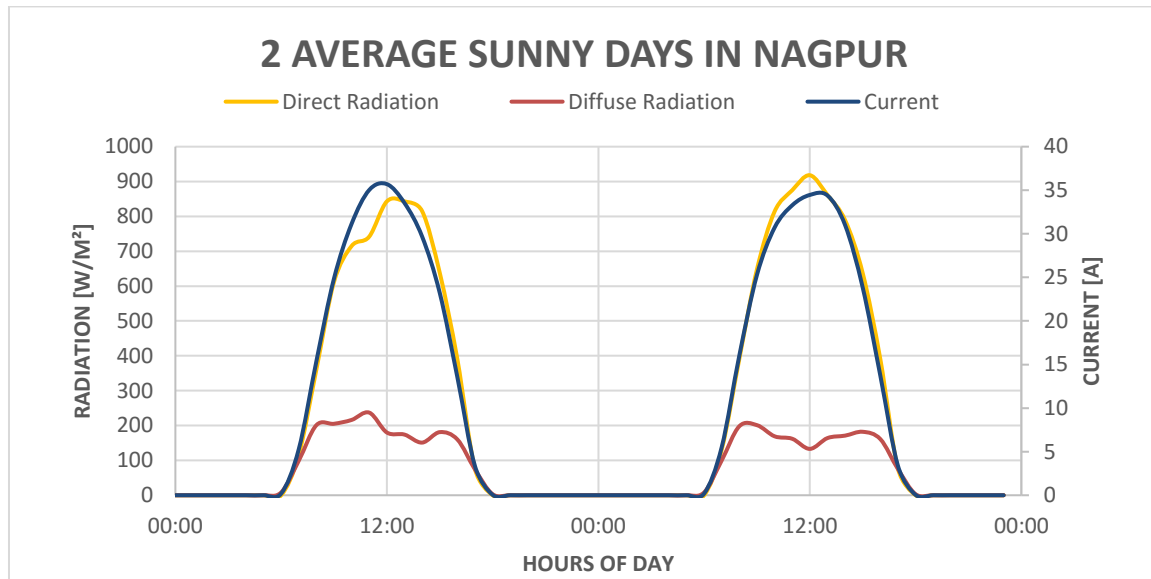


Figure 11: Irradiance and generated current for two consecutive average days in Nagpur [3]

For the worst irradiance scenario, the required Ampere-hours could also be generated using the 420 W panels. The results of the simulation shown in Fehler! Verweisquelle konnte nicht gefunden werden.⁸ show that on three consecutive winter days, 494 Ampere hours could be generated.

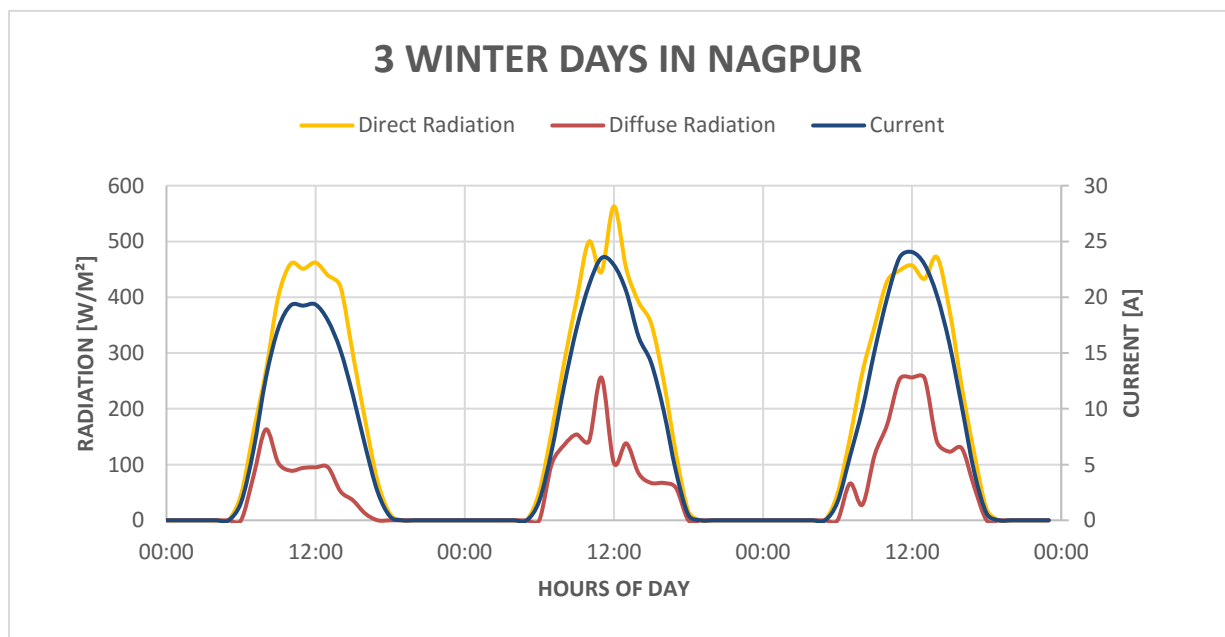


Figure 8: Radiation and generated current of three consecutive winter days in Nagpur [3]

3.3 Madoi Huangheyan (China)

Madoi Huangheyan is located in the center of China, on the northern hemisphere. Therefore, azimuth angle was set to 180° . As in the previous simulations, the tilt angle was set to 30° . The results obtained, shown in **Figure 129**, revealed that in two consecutive average sunny days, 493 Ampere-hours could be generated with 360 W of panels.

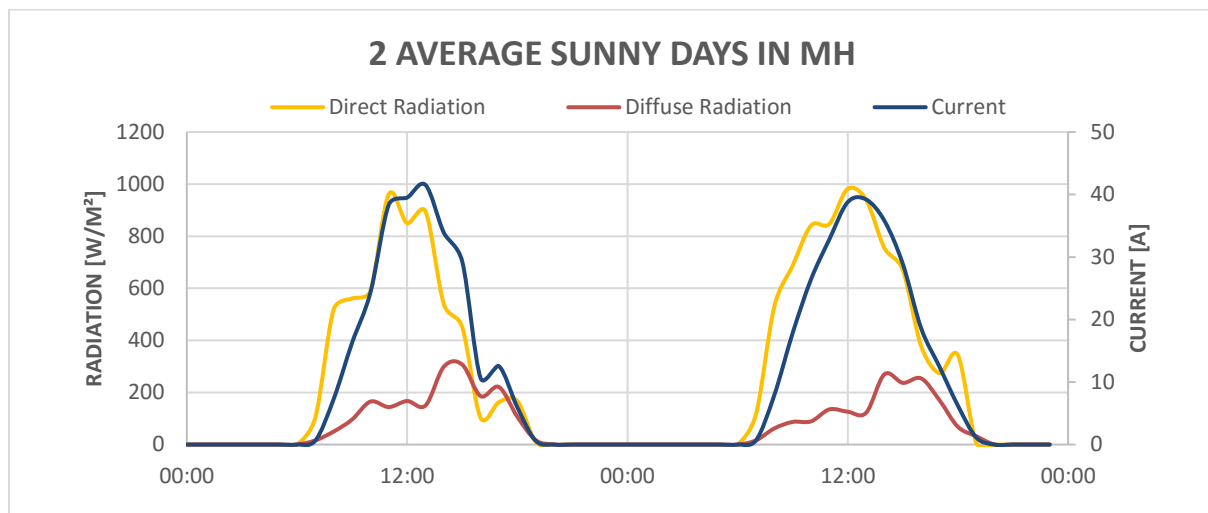


Figure 12: Irradiation and generated current of two average days in Madoi Huangheyan [3]

Considering now 3 days with the lowest irradiance, an amount of 568 Ampere-hours could be generated with the same panels. The results from the simulation may be seen in **Figure 1310**.

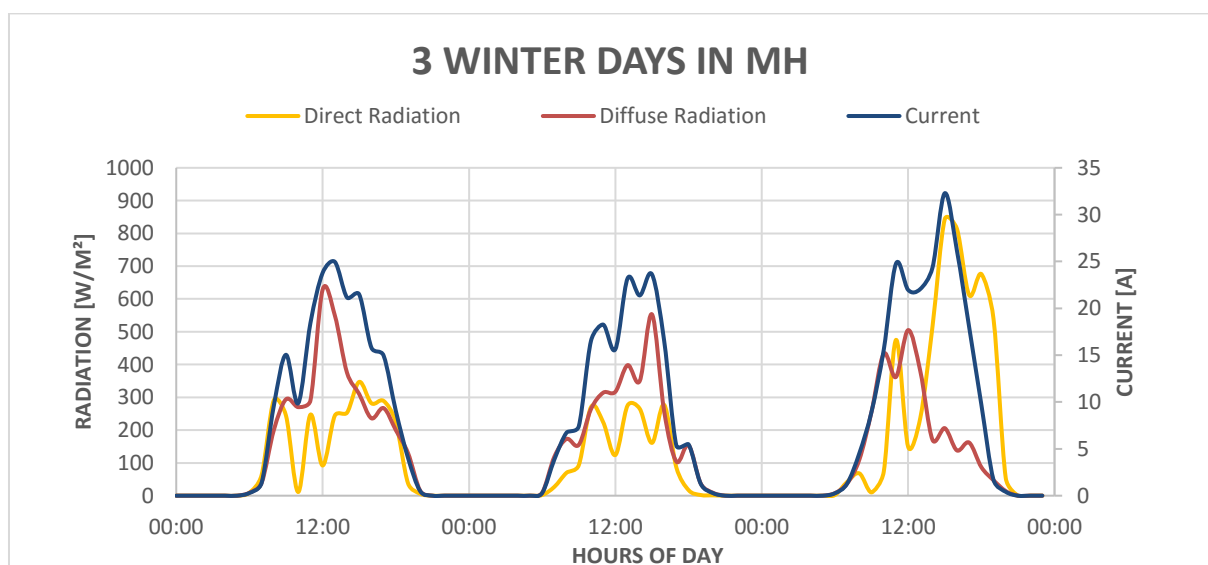


Figure 13: Irradiance and generated current for three consecutive days in Madoi Huangheyan [3]

4 Connection between PV panels and electrolyzer

Basically, there are two different alternatives regarding how to connect PV panels with a consumer that needs direct current as a power source. One option is to connect the panels directly to the consumer. The other one is to use a battery in between.

4.1 Direct Connection

This option is the simplest because apart from the panels, no other components are needed (**Figure 14**). Nevertheless, it is important to match panel and consumer characteristics in order not to lose too much energy. Regarding the panels, only if the operating point is close to the maximum power point (MPP) the solar cells will have a good efficiency.

A problem of this type of connection is that it is impossible to determine the progress of the process. Consequently, an Ampere-hour meter is needed. The device integrates current over time and therefore shows the amount of Ampere-hours provided to the electrolyzer. Thus, by measuring the current supplied to the electrolyzer with time, it is possible to determine when the desired chlorine concentration is reached. [4]

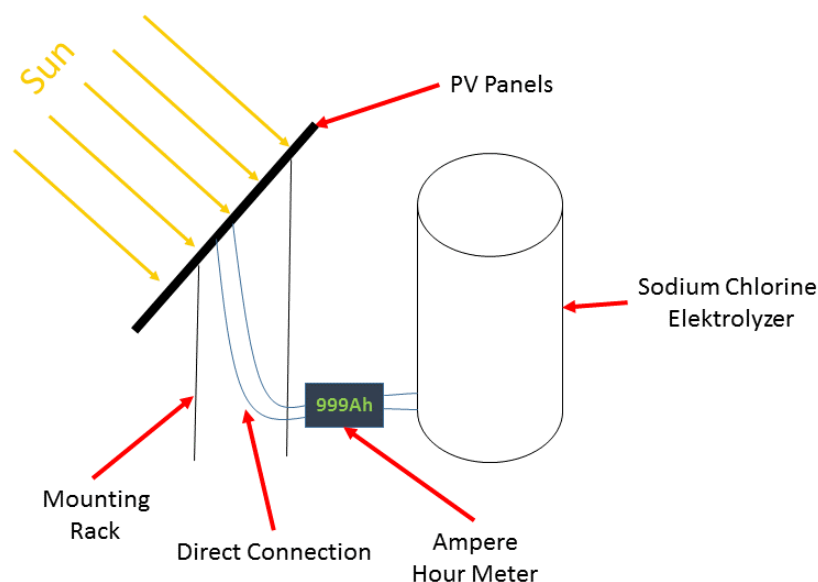


Figure 14: Scheme of the direct connection from the panels to the electrolyzer

4.1.1 Option 1

First logical solution to match panel characteristic and cell characteristic was to use a panel with an MPP at approximately 8 Volt. From the approximated machine characteristic of **Figure 4** it is apparent that 8 Volt is the corresponding voltage to the maximum generated current of the panels of 32 Ampere (**Figure 8**) [5]. This means a efficiency of energy usage of 86%.

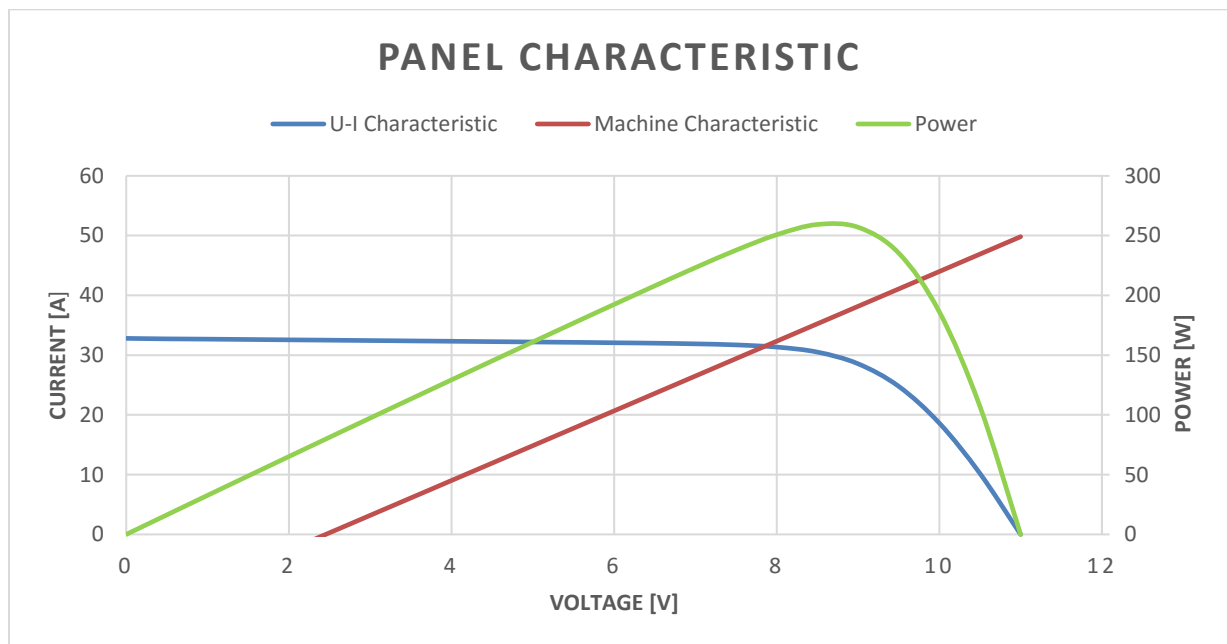


Figure 15: Panel characteristics [3]

4.1.2 Option 2

Due to the fact that 8V-panels are hard to acquire. An idea was to use standard 12V-panels with a MPP at approximately 15V. These panels are easy to acquire and compared to 8V panels considerably cheaper. Drawback of this solution however is that the operation point is far away from the MPP. This means that to generate the needed 456 Ah approximately 700W of panels is needed, which is considerably more than in the other options.

4.2 Connection with Converter

4.2.1 Option 3

This concept adds additionally a converter which converts panel voltage to the required electrolyzer voltage of 8-9 V. This eliminates the drawback of Option 2. However, due to the use

of a converter, which has an efficiency of 85%, more installed power is necessary. So for this solution approximately 425 W panels are needed. Advantage is that in this case panels with higher voltage and higher efficiency can be selected. To measure the progress of the process like before an Ampere hour meter is used [6].

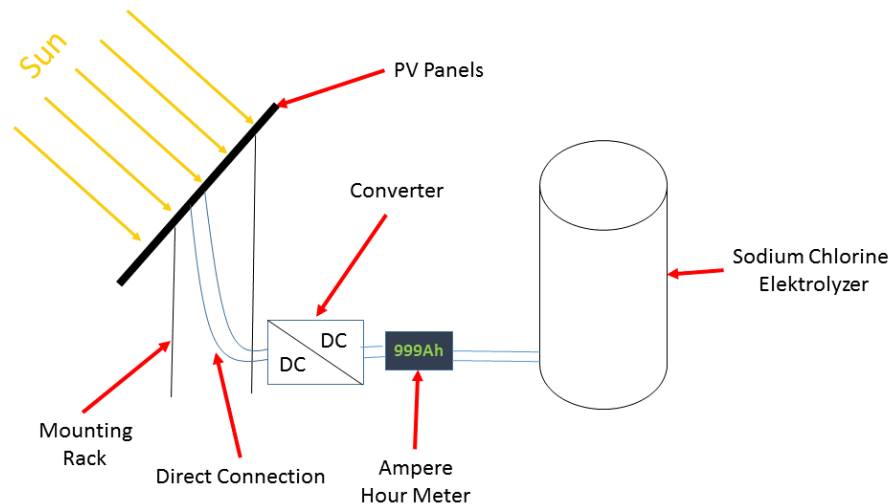


Figure 16: Schema of connection with converter

4.3 Connection with Battery and Converter

Most non grid connected PV systems use a battery to be able to deliver energy also during night hours. Though the system design of this connection methods requires more components.

The first question that had to be answered was the size of the battery. There are two solutions. The first one uses only a small battery which stores only the amount of energy that is over a certain value of current. The second solution stores all the collected energy [7].

4.3.1 Option 4

The advantage of using a battery is that the process conditions can be controlled. This means that the highest flowing current can be limited. All the energy that would produce a higher current can be saved in the battery and used in times with lower energy flow. If the maximum current is limited to 25 Ampere the Ampere hours that had to be saved were calculated to 34 Ah. With a puffer capacity of 30% that will extend battery lifetime a battery size of 50Ah would be sufficient for this solution [7].

To charge the battery and protect it from overloading a charge controller is needed. It transfers the panel voltage to battery voltage and also protects battery from too deep discharge. Furthermore a converter is needed to convert battery voltage to needed consumer voltage and current. In this case a converter from 12 Volt to 7 Volt is used. Like in the option with direct connection an Ampere hour meter is used to measure process progress. **Figure 17** shows the schema of this solution.

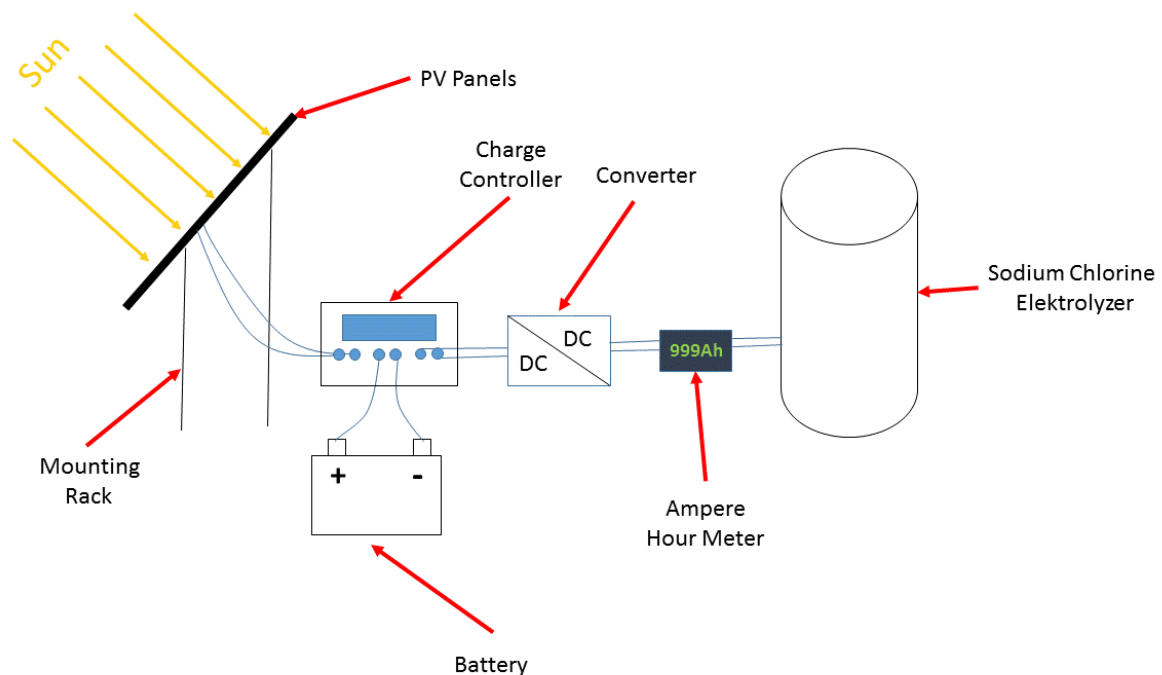


Figure 17: Schema of connection with battery

4.3.2 Option 5

In this case it was decided to use a battery capacity of 600 Ah. This can store the required 456 Ah necessary for one complete process and includes 30% bigger capacity puffer. With this capacity the whole energy can be stored in the battery and the process can be done afterwards with constant conditions at 20 Ampere over 24 hours.

The remaining structure is the same as in Option 4. Only the converter operates on a different voltage because the process current in this case is only 20 Ampere which means an operating point at approximately 6 Volt. Because of the controlled conditions and the measurements done in chapter 2.4 the process progress can be determined only by the time of the process.

[7]

4.4 Other Options

To reduce the required Ampere hours an idea was to reduce the amount of sodium chlorine solution in the electrolyzer. With a third of the original amount the required Ampere hours also would be a third of the original amount. This option would make it possible to finish the process in one day without using more panels. To validate this hypothesis an experiment with only 10 liters of sodium chlorine solution was made.

The procedure of the measurements was the same as in chapter 2.4. Every hour one sample was taken. The results in Figure 18 show that the efficiency with fewer sodium chlorine solution is lower than with more solution. The process in this set up only reaches an efficiency of 40%. Due to this reason it was decided not to use the option to reduce the amount of solution used in the electrolyzer.

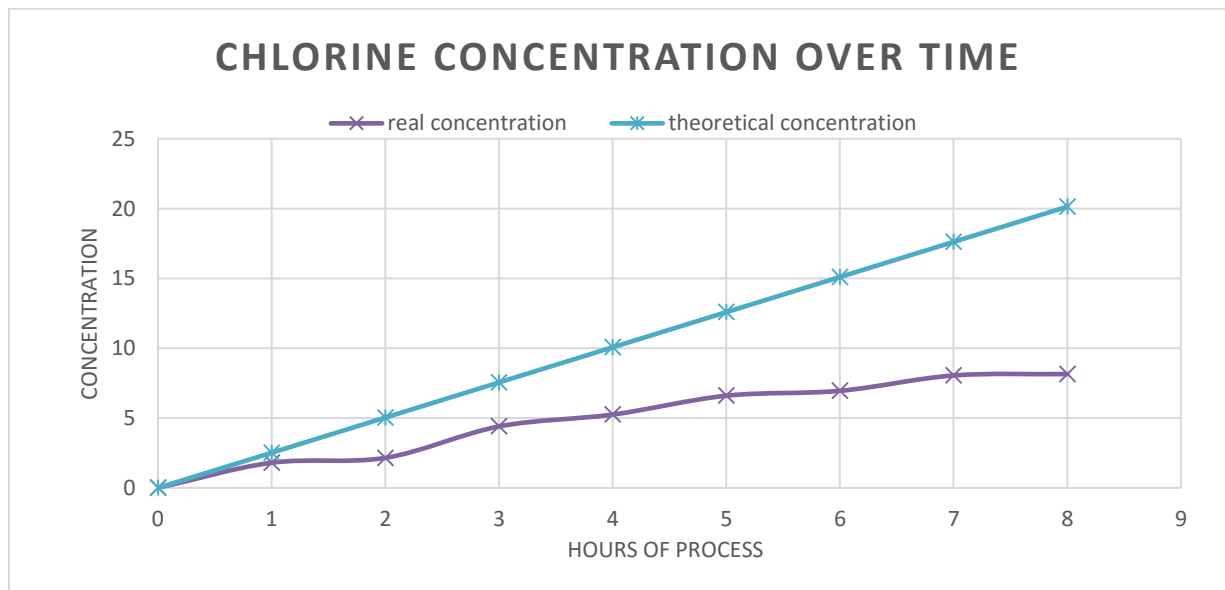


Figure 18: Chlorine concentration over time with 10 liter of sodium chlorine solution

5 Discussion

To decide which option is the most suitable for the problem both concepts were rated in different criteria. To rate the concepts the in **Table 1** shown rating scale was used.

1	2	3	4	5
very bad	bad	sufficient	good	very good

Table 1: Rating scale

The options were rated in the criteria efficiency, costs, possibility to measure process progress, area of panels and duration of process. All criteria were equally weighted the same except of costs which was weighted double.

	Option 1	Option 2	Option 3	Option 4	Option 5
Criteria	Direct Connection 8 V Panel	Direct connection 12 V Panel	Use of converter	Small Battery for energy over 25 A	Use of battery and storage of total energy
Efficiency	5	2	4	3	3
Costs (x2)	2	4	5	4	1
Possibility to measure process progress	4	4	4	4	5
Area of panels	4	2	4	3	3
Duration of process	5	5	5	5	3
Sum	22	21	27	23	16

Table 2: Rating of the two concepts

In the view of efficiency option 1 is the best because the operation point is very close to the MPP of the panels. Furthermore there are no additional components which can lower the total efficiency. Option 3 has one additional component which lowers the overall efficiency and option 4 and 5 have two more components. This explains the lower ratings in efficiency. The most inefficient solution is the use of 12 Volt panels. The MPP of these panels is at approximately 15V which means that only about 40 % of the panel energy can be used when the operation point is at about 8-9 Volt.

To evaluate the costs of the different solutions real prices were investigated and the various concepts were rated in the order of the costs of the whole solution. **Table 3** shows the price rating of all the different options. A minus (-) means that this option does not have this component. All prices are in US Dollar (US\$). Option 2 and 4 were rated the same because of the small difference in price between these options.

Components	Panels	Converter	Battery	Charge Controller	Total Cost	Rating
Option 1	720\$	-	-	-	720\$	2
Option 2	315\$	-	-	-	315\$	4
Option 3	210\$	70\$	-	-	280\$	5
Option 4	162\$	39\$	100\$	20\$	321\$	4
Option 5	162\$	27\$	1000\$	20\$	1209\$	1

Table 3: Price rating of all options

In option 1-4 an Ampere hour meter is used to determine the progress of the process. That is why all these options are rated the same. Only in option 5 the progress can be determined by time only because there are constant conditions the whole 24 hours.

The panel size is directly related to the efficiency of the solution. This is why option 2-5 are rated the same as in efficiency. Only option 1 was rated one point less than in efficiency. This is because of the lower panel efficiency of low voltage panels.

An advantage of option 5 is that you can first collect the energy needed and then run the whole process for 24 hours without breaks during the process in which the concentration of chlorine will decay. But because of that the total process needs time to collect the required Ampere hours plus the 24 hours of process. Whereas the process time of option 1-4 is only the time that is needed to collect the required Ampere hours because the energy is not stored in batteries in between.

The overall best rated solution is option 3. This option combines a good efficiency and a simple structure. On the basis of the good efficiency the panel size is compared to the other concepts the smallest. But most important, option 3 is the most economical because cheapest solution. This is why it was decided to use this concept to connect panels and electrolyzer.

As known from chapter 4.2 425 Watt panel size is needed. The search for fitting converters to the required 9 V Voltage resulted in the decision to use two converters with 30 A maximum current. This means that the 425 Watt of panels have to be split in two panels that are parallel

connected. Since there are no 212,5 W panels it was decided to use two 250 W panels. These panels are standard size and therefore can be acquired economically.

It follows that for the given requirements the prototype of the electrolyzer will be powered by two 250 W - 24 V panels from the Bestsun solar panel company from China. Both panels will have a 24V to 9 V converter with maximum current of 30 A from Empire-RC that converts the panel voltage to the operating voltage of thez. To determine the progress of the colorization process a HB 404 DC AH Meter will be used.



Figure 19: Bestsun Solarpanel [8]



Figure 20: Buck Converter (left) [9], Amper hour meter (right) [10]

Validation of the here made calculation and assumptions will be done in the continuing work of Safia Bassi.

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Appendix

Measurements Electrolyser Characteristic

T = T_{amb} = 20 °C	
Current [A]	Voltage [V]
0	2,3
1	2,9
2	3,1
3	3,3
4	3,5
5	3,7
6	3,8
7	4
8	4,2
9	4,4
10	4,5
11	4,7
12	4,8
13	5
14	5,2
15	5,3
16	5,5
17	5,6
18	5,8
19	6
20	6,1
20,81	6,2
T = 42 °C	
Current [A]	Voltage (V)
0	2,3
1	2,8
2	2,9
3	3,1
4	3,3
5	3,4
6	3,5
7	3,7

8	3,8
9	4
10	4,1
11	4,2
12	4,3
13	4,5
14	4,6
15	4,7
16	4,8
17	4,9
18	5,1
19	5,2
20	5,3
20,78	5,4

After 24hs at
19A (T = 35
°C)

T = 42 °C	
Current [A]	Voltage [V]
0	1,4
1	2,2
2	2,5
3	2,8
4	3
5	3,2
6	3,4
7	3,5
8	3,7
9	3,8
10	4
11	4,1
12	4,3
13	4,4
14	4,5
15	4,7
16	4,8
17	4,9
18	5,1
19	5,2
20	5,3

20,71	5,4
T = T_{amb} = °C	
Current [A]	Voltage [V]
0	1,4
1	2,3
2	2,7
3	3,1
4	3,4
5	3,6
6	3,8
7	4
8	4,2
9	4,5
10	4,7
11	4,9
12	5
13	5,2
14	5,4
15	5,6
16	5,8
17	6
18	6,1
19	6,3
20	6,5
20,74	6,6

Approximation Electrolyser Characteristic

		a	b
T _{amb}	$y = 5,7539x - 15,637$	5,7539	-15,637
T=42	$y = 7,2816x - 19,265$	7,2816	-19,265
T _{amb} after process	$y = 5,8474x - 12,424$	5,8474	-12,424
T=42 after process	$y = 4,4329x - 9,8829$	4,4329	-9,8829
	average	5,82895	14,302225

Measurement Chlorine Concentration

Hs of process at 19A	CC		CC _{agua}		CC _{real}		CC _{teo}		Efficiency (%)	Current [A]	Voltage [V]
0	0	ppm	0	ppm	0,00	g/l	0,00	g/l	-	19	6,60
1	0,67	ppm	0,5	ppm	0,85	g/l	0,84	g/l	101,32	19	6,00
2	0,79	ppm	0,52	ppm	1,35	g/l	1,68	g/l	80,46	19	5,50
3	0,92	ppm	0,58	ppm	1,70	g/l	2,52	g/l	67,55	19	5,30
4	0,96	ppm	0,52	ppm	2,20	g/l	3,36	g/l	65,56	19	5,30
5	1,16	ppm	0,52	ppm	3,20	g/l	4,19	g/l	76,29	19	5,10
20	2,07	ppm	0,22	ppm	8,51	g/l	16,78	g/l	50,72	19	5,10
21	2,22	ppm	0,43	ppm	8,95	g/l	17,62	g/l	50,80	19	5,20
22	2,32	ppm	0,42	ppm	9,50	g/l	18,46	g/l	51,47	19	5,20
23	2,63	ppm	0,39	ppm	10,30	g/l	19,30	g/l	53,40	19	5,00
24	2,49	ppm	0,41	ppm	10,40	g/l	20,13	g/l	51,65	19	5,10

Measurement Chlorine Concentration with 10 liters

Hs of process at 19A	CC		CC _{agua}		CC _{real}		CC _{teo}		Efficiency (%)	Current [A]	Voltage [V]
0	0	ppm	0	ppm	0	g/l	0,00	g/l	-	19	6,9
1	0,55	ppm	0,19	ppm	1,8	g/l	2,52	g/l	71,52	19	6,3
2	0,74	ppm	0,31	ppm	2,15	g/l	5,03	g/l	42,71	19	5,6
3	1,11	ppm	0,23	ppm	4,4	g/l	7,55	g/l	58,28	19	5,4
4	1,99	ppm	0,24	ppm	8,75	g/l	10,07	g/l	86,92	19	5,4
5	1,66	ppm	0,34	ppm	6,6	g/l	12,58	g/l	52,45	19	4,8
6	1,87	ppm	0,48	ppm	6,95	g/l	15,10	g/l	46,02	19	4,8
7	2,03	ppm	0,42	ppm	8,05	g/l	17,62	g/l	45,69	19	4,9
8	2,12	ppm	0,49	ppm	8,15	g/l	20,13	g/l	40,48	19	4,8

Measurement of decay of the chlorine concentration

Hs after process	CC			
0	2,15	ppm (1ml en 5lts)	10,75	g/l
18	1,88	ppm (1ml en 5lts)	9,4	g/l
90	1,48	ppm (1ml en 5lts)	7,4	g/l
185	1,01	ppm (1ml en 5lts)	5,05	g/l

Dimensioning Panels 8V

Hour	E [W]	I [A]	V_real [V]	I_real [A]	E_real [W]	Efficiency	0,86098905
07:00	8,37153	1,0538852	2,63445564	1,0538852	2,77641382	More power	0,16145496
08:00	57,7449	7,26945919	3,70078388	7,26945919	26,9026974		
09:00	131,832	16,5962248	5,30086033	16,5962248	87,9742699		
10:00	194,397	24,4724825	6,65209129	24,4724825	162,793188		
11:00	263,112	33,1229588	8,13614525	32	254,191784		
12:00	257,147	32,3720298	8,00731774	32	254,191784		
13:00	253,268	31,8837056	7,92354207	31,8837056	252,631882		
14:00	236,91	29,82441	7,57025451	29,82441	225,778375		
15:00	196,073	24,6834728	6,68828826	24,6834728	165,090182		
16:00	138,545	17,441319	5,44584257	17,441319	94,9826775		
17:00	67,3269	8,47572949	3,90772858	8,47572949	33,1208503		

Dimensioning Panels 12V

hour	E [W]	I [A]	Vreal [V]	Ereal [W]		
07:00	0,00759601	0,50640067	2,54053057	1,28652637	Efficiency	0,41235272
08:00	0,0931039	6,20692667	3,51849847	21,839062		
09:00	0,211836	14,1224	4,87645717	68,8672787		
10:00	0,311666	20,7777333	6,01822941	125,045166		
11:00	0,356302	23,7534667	6,52873874	155,080178		
12:00	0,395977	26,3984667	6,98250828	184,327512		
13:00	0,420139	28,0092667	7,25885308	203,315152		
14:00	0,385928	25,7285333	6,86757621	176,692663		
15:00	0,326835	21,789	6,19171978	134,911382		
16:00	0,218849	14,5899333	4,95666601	72,3174266		
17:00	0,0951624	6,34416	3,54204188	22,4712804		
18:00	0,00790655	0,52710333	2,54408227	1,34099424		

Dimensioning Battery

I	I > 20A	I > 25	I > 30
1,04644125	0	0	0
7,2181125	0	0	0
16,479	0	0	0
24,299625	4,299625	0	0
32,889	12,889	7,889	2,889
32,143375	12,143375	7,143375	2,143375
31,6585	11,6585	6,6585	1,6585
29,61375	9,61375	4,61375	0
24,509125	4,509125	0	0
17,318125	0	0	0
8,4158625	0	0	0
1,5902125	0	0	0

Current of process	20 A	25A	30A
Ah battery (+30% reserve)	71,6473875	34,1960125	8,6981375
convertidor	http://www.ebay.com/itm/DC-12V-24V-to-6V-20A-120W-STEP-DOWN-DC-DC-Power-Converter-Regulator-/390805682663	http://ec2-52-87-233-102.compute-1.amazonaws.com/item/B00RSOO-BYC/SMAKN-Converter-11-40V-Supply-Module	
Price Converter	27 US\$	39 US\$	
Cost 50 Ah deep cycle battery	100 US\$		
Charge controller	http://www.ebay.com/itm/10-20-30A-PWM-LCD-Solar-Panel-Charge-Controller-12V-24V-Battery-Auto-Regulator-/121962565507?var=&hash=item1c65890f83:m:mRo3ibNm8OhMT-bxAC0hFzLw	14 US\$	