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Master in Energy and Environment
Thesis Work

FLOATING DISPLACEABLE SOLAR PV-PLANT
TO STUDY THE WATER ECOSYSTEM AT THE RESERVOIR
OF SALTO GRANDE HYDROELECTRIC

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Summary

This thesis proposes the design of a solar PV floating, displaceable power plant, for mainly two applications which could be of interest for the Salto Grande Hydroelectric: study of the ecosystem at the dam water reservoir and possible uses as pilot platform for technical capacitation. – Details are given for the dimensioning of the plant, the selection of the PV-panels, electronic equipment and batteries, as well as for space and costs optimization. Further analysis concerning the characterization of the Salto Grande water Reservoir and its ecosystem is stated. A boat design is proposed and useful references are given of existing floating solar PV plants in the world.

Resumen

Esta tesis propone el diseño de una planta de energía solar fotovoltaica, flotante y desplazable, para principalmente dos aplicaciones que podrían ser de interés para la Hidroeléctrica Salto Grande: el estudio del ecosistema en el embalse y posibles usos como plataforma piloto para capacitación técnica. - Se proporcionan detalles sobre el dimensionamiento de la planta, la selección de paneles fotovoltaicos, equipos electrónicos y baterías, como también para la optimización del espacio y los costos. Un análisis más detallado se refiere a la caracterización del embalse de Salto Grande y su ecosistema. Se propone un diseño de barco y se proporcionan referencias útiles de plantas solares fotovoltaicas flotantes, ya existentes en el mundo.

Zusammenfassung

Diese Masterarbeit schlägt den Entwurf eines schwimmenden, verschiebbar Solar-PV-Kraftwerk vor, das hauptsächlich für zwei Anwendungen von Interesse sein könnte: die Untersuchung des Ökosystems am Staudammwasserspeicher und mögliche Pilotplattform für technische Ausbildung. Es werden Einzelheiten zur Dimensionierung der Anlage, zur Auswahl der PV-Module, elektronischen Geräte und Batterien, sowie zur Raum- und Kostenoptimierung angegeben. Weitere Analysen betreffen die Charakterisierung des Salto Grande-Stausees und seines Ökosystems. Ein Bootskonzept wird vorgeschlagen und nützliche Referenzen von existierende schwimmende Solar-PV-Anlagen auf der Welt werden angezeigt.

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Abbreviations

AC	Alternative Current
AGM	Absorbent Glass Matt
CARU	Comisión Administradora del Río Uruguay
DC	Direct Current
DoD	Depth of Discharge
E	Energy
G	Irradiation
GHG	Greenhouse Gas Emission
GSM	Global System for Mobile Communication
GW	Giga Watt
I	Current
Impp	Current at MPPT
INTA	Instituto Nacional de Tecnologia Agropecuaria
Isc	Short Circuit Current
kW	Kilo Watt
MPPT	Maximum Power Point
MW	Mega Watt
NPSH	Net Positive Suction Head
P	Power
Pmax	Maximum Power
PMSM	Permanent Magnet Synchronous Motor
PV	Photovoltaic
RECAI	Renewable Energy Country Attractiveness Index
SMPS	Switched-Mode Power Supply
SoC	State of charge
t	time
V	Voltage
Vmpp	Voltage at MPPT
Voc	Open Circuit Voltage
VRLA	Valve Regulated Lead Acid
WHO	World Health Organization

1. Introduction

The following contents will be analyzed in this section:

1.1. Concepts of Solar PV Energy
1.2. Method to Design a PV Solar Project
1.3. Relevance of Solar PV Electricity in Argentina
1.4. Environmental Situation at Salto Grande Dam
1.5. Characterization of the Salto Grande Water Reservoir
1.6. Existing floating solar PV plants around the world

1.1. Solar PV Energy
1.1.1. Why Solar PV Energy?

There are several reasons why the installation of a Solar Photovoltaic system is beneficial. Benefits can range from environmental, energetic stability, the creation of jobs to a more competitive energy market.

The PV Systems offer an energy supply with a smaller environmental impact compared to other means of generating electricity. Through the whole life cycle process, the PV systems produce not only less Greenhouse Gas Emissions (GHG), but also smaller water and air emissions too. Moreover, the visual impact and noise pollution are significantly smaller compared to other methods.

Energetic stability is of vital importance to assure a more secure electric network. Argentina has small communities that are only supplied by a one-way medium tension cable. This situation makes the electrical supply very unstable resulting in fluctuating residential tension that affect the day to day life of the inhabitants. A PV Solar system gives not only electricity but also stability to the grid.

Furthermore, there are several secluded communities in Argentina that have very limited access to the electric network or that are supplied only by a Diesel Engine. This situation is aggravated by the fact that the fuel necessary to power these Diesel engines is only supplied once every two weeks, meaning that in order to ensure a longer availability of the energy, the inhabitants of these communities must ration the electricity.

The Solar PV system helps to ensure a long term electric supply, completely eliminating the need of a Diesel Engine and therefore eliminating unnecessary GHG emissions.

1.1.2. Environmental Life Cycle of a Solar Panel

The life cycle of a solar panel starts on a quartz mine with silica sands and quartz. These sands are first thermally treated in order to obtain the silica liquid that is accumulated in the bottom of the furnaces and is later submitted to a purification treatment to obtain Silica at 98% purity.

The next step, for a normal solar PV cell, is crystallization. After this process is completed the cell is produced and later used in the model assembly to finalize the solar panel process.

This process is described in the diagram on Figure 1:
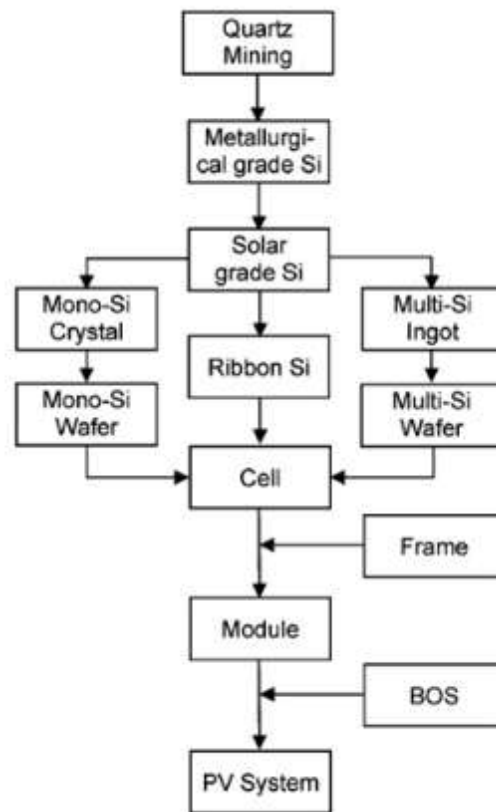
Figure 1 Diagram of the production of a solar PV Panel.
Source: Moreno Martin, 2016

The amount of GHG emissions from the Solar Panel production has not yet been determined, however the following case studies can be used in order to estimate a numerical value based on the semiconductors used during the process.

- Case 1: Estimation based on the electricity employed for the production of silica using the Ecoinvent database and the Crystal Clear project.

- Case 2: Emission corresponding to the media for the European Network.

- Case 3: Emission corresponding to the media for the EEUU Network.

Figure 2 compares the CO_2 emissions in each of these cases.
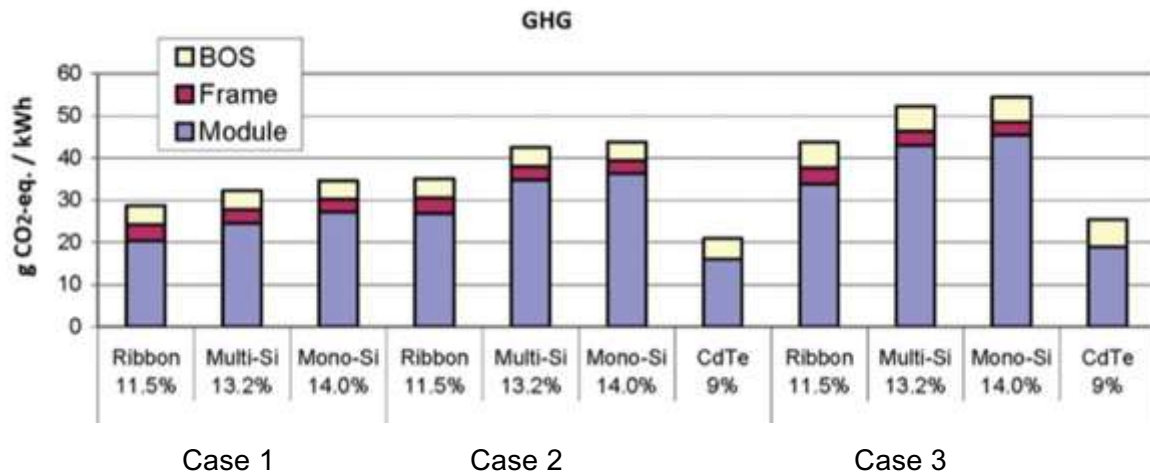
Figure 2 Equivalent CO$_2$ emissions per kWh generated depending on the solar PV material used.
Source:Vasislis M. Fthenakis and Alsema, 2007

From the graphic arises that the monocrystalline Silica is the one that produces most equivalent CO$_2$ emissions. It is important to highlight that once the silica solar panels have fulfilled their life cycle, they can be recycled and up to 80% of the panel can be reused.

Finally, it is important to keep in mind that once the solar Panel is working, unlike conventional methods, the panel will not emit any more CO$_2$ emissions

1.1.3.   Concepts of Solar PV Energy

Photovoltaics is the most effective way of converting solar irradiation into electricity by the creating an electric voltage between two electrodes attached to a solid or liquid system.

All solar cells are made of a semiconductor and a p-n junction. The semiconductor matrix is capable of absorbing light, and depending on the material used, it will be able to absorb more or less of the solar spectrum.

When the light shines upon the solar cell an electron-hole pair is created. If recombination does not occur, the pair reaches the electric field created by the p-n junction and is forced to separate.

Figure 3 illustrates the basic solar cell structure.
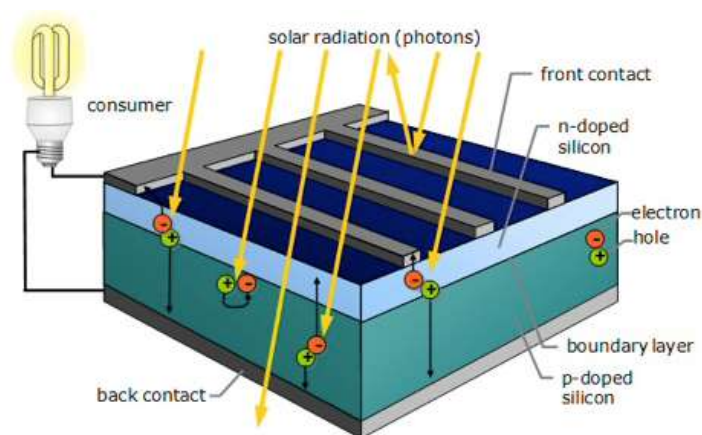
Figure 3 Basic Structure of a Solar Cell.
Source: https://www.volker-quaschning.de/articles/pv-basics/index.php

For a solar cell to work, semiconductors must be used, not metallic conductors. The reason for this is that the band gap required to create an electron-hole pair on metals is very high, meaning that the conduction band (where electrons will move) and valence band (where holes will move) will have a higher energy level separation, resulting on the need for more energy to create an electron-hole pair. Some metals even have both bands mixed up, making them useless to conduct electricity.

Whereas on semiconductors, the band gap between the valence band and the conduction band is narrower, meaning that a solar radiation is enough to provide the necessary energy and the electron-hole pair can be easily conducted. Another important aspect to keep in mind is that on higher temperatures the conductivity of metals tends to decrease, while on semiconductors it tends to increase, making them more efficient choice.

The most popular semiconductor used is silicon, not only because of its conductive properties or because it can absorb a wider range of the solar spectrum, but mainly because it is highly abundant on Earth.

Figure 4 illustrates the energy that can be used by Silicon solar cell.
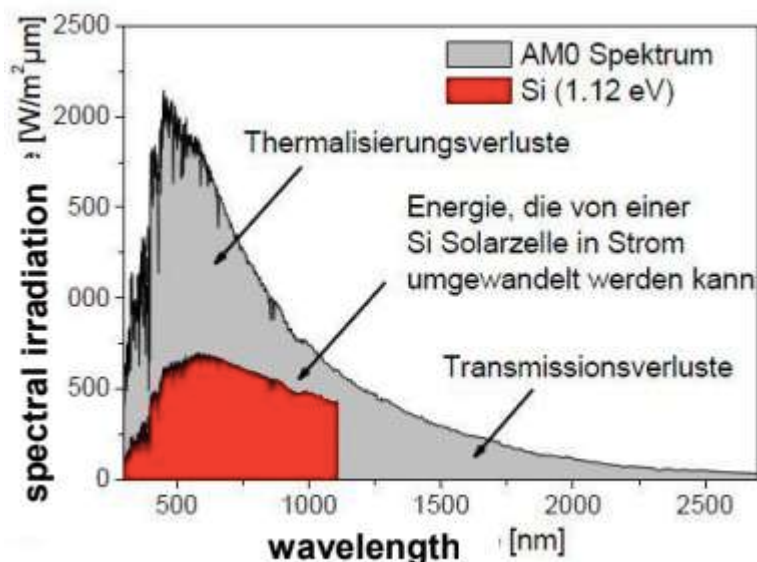
Figure 4 Solar Spectrum at AM0, and the energy that can be used by a Silicon solar cell.
Source: KIT - Course: Fundamentals of Energy Technologie.

There are three basic Silicone arrangements: Monocrystalline, Polycrystalline and Amorphous Silicon.

- Amorphous:
    - Does not have a defined structure, resulting in a more flexible and light material.
    - Can handle higher temperatures better.
    - Performs better in low light conditions compared to crystalline cells.
    - Least efficient.

- Monocrystalline:
    - Near perfect structure, resulting in a more rigid material.
    - It's the most expensive.

- o Has the longest life cycle
- o Most popular due to its higher efficiency and life cycle.

- Policrystalline:
    - o Its structure is a combination of the previous arrangements, having places with order and other with no order at all.

In order to enhance the solar cell efficiency a p-n junction is applied. A p-n junction will create an electromagnetic field that will help to separate the electron-hole pair and prevent its recombination.

For the n-junction, the silicon is doped mainly with Phosphorus in order to bring the conduction band closer to the Fermi level and make it more likely to have electrons on the conduction band.

For the p-junction, the silicon is doped mainly with Boron in order to bring the valence band closer to the Fermi level and make it more likely to have holes on the valence band.

Figure 5 illustrates a p-n junction.
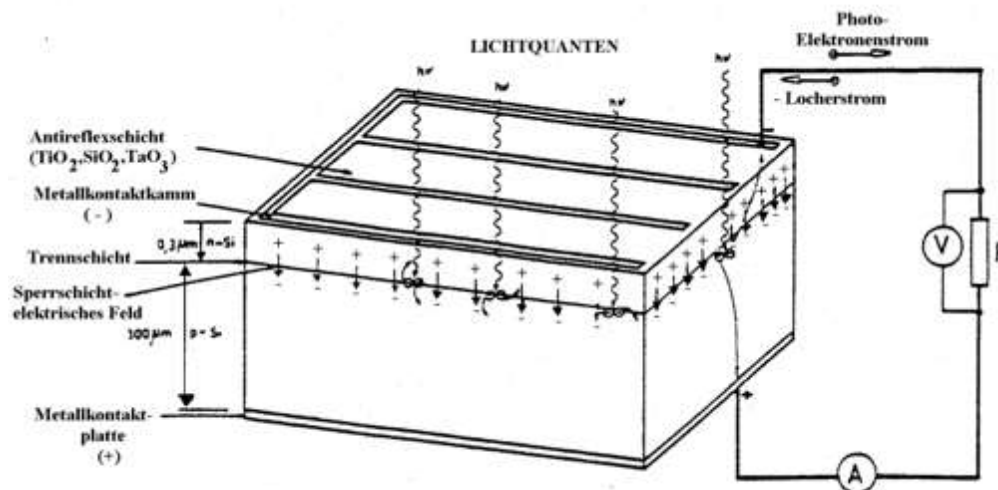
Figure 5 p-n junction on a Solar cell.
Source: KIT - Course: Fundamentals of Energy Technologie

One of the most important characteristics of a solar cell is its I-V curve, which represents the necessary current for a specific voltage. The Maximum Power Point (MPP) is the point on the curve where the product of current and voltage is at maximum power. See Figure 6.
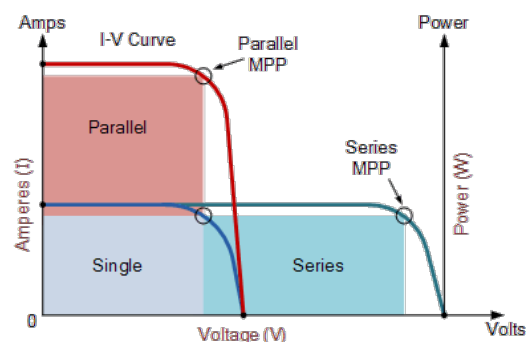
Figure 6 I-V curves for a single solar cell, Solar cells connected in series and solar cells connected in parallel.
Source: http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html

The MPP gives you the value of the I_{MP} (maximum current on MPP) and the V_{MP} (maximum Voltage on MPP).

Other important values to consider are the Short Circuit Current (I_{SC}), defined as the maximum current the cell can withstand (null voltage) and the Open Circuit Voltage (V_{OC}), defined as the maximum voltage the cell can withstand (null current).

All this data must be provided by the manufacturer of the solar PV panel.

A solar panel is a collection of solar cells, where some cells are connected in parallel and other cells are connected in series. The parallel connection will give a higher current, while the series connection will increase the voltage.

Figure 7 illustrates a commercial solar panel of 72 solar cells and a power peak of around 320 W.

Figure 7 Image of a commercial 320 pW solar panel.
Source: Jinko Solar

Finally, it's important to mention that depending on the manufacturer, a commercial solar panel can reach an efficiency of around 16-23%.

1.1.4.   Battery Storage

Battery storages are not always contemplated since big solar PV projects tend to give electricity to the network only when it's available and do not even produce any at night.

The necessity for a battery storage depends solely on the customer needs. For example, if the customer wishes to be independent of the network a battery system is certainly needed, however if the customer wishes to inject any residual energy directly to the network, then there is no need for a battery system.

Some customers might even prefer the latter case if they can later receive a discount on their electric bill, as is the case for countries such as Germany and Spain.

Argentina currently has a legislation regarding distributed energy, but no regulation yet on this subject.

For the purpose of this project a battery system will be needed as there is a space restriction on the solar boat which limits the amount of panels that can be installed. This means that on a cloudy day the boat will not be able to produce enough energy and the stored energy will be needed. Also, since the whole system is disconnected from the network, it won't be able to receive energy from the grid if necessary.

Having said this, it is important to highlight that the feasibility of the whole system highly depends on the correct design of the storage capacity.

Although multiple types of batteries can be found today in the market, the most popular one is the Lead Acid battery due to its low maintenance and its high depth of discharge. This type of battery uses a reversible chemical reaction that allows them to be charged and then discharged.

The following aspects must be taken into account at the moment of selecting a battery:

- Life cycle of the Battery: process of charge and discharge of a battery.
- Storage: capability to store energy, it's usually expressed as ampere-hour (Ah).
- State of charge (SOC): amount of energy capable of being used in relation to the energy stored.
- Efficiency:

    It can be divided in two:

    - Voltage: ratio between the voltage during battery charge and discharge.
    - Charge: ratio between the ampere-hour during battery charge and discharge.

For the correct design of the battery storage, the following parameters are essential:

- Maximum Depth of Discharge (DoD): maximum level of tension that the regulator allows before the battery disconnects due to the overdischarge controller. The more energy used from a battery, the more the life cycle is affected, resulting in a lesser energy capacity on the next charge.

    There are two key aspects to take into account:

    - Maximum Daily DoD: how much energy can be discharged from the battery during a clear sky day. It is recommended to use about 20% of the battery.
    - Maximum Stationary DoD: how much energy can be used from a battery when no sun shines for a long period of time. For Lead Acid batteries it's recommended to use a 70% DoD.

- Autonomy: Represents the amount of consecutive days that the batteries should be the sole provider of energy to the system. Normally, a 5 to 6 day period is used.

There are two types of Lead Acid Batteries: AGM (Absorbent Glass Matt) and Gel Batteries.

Both types of batteries are of low maintenance and leakage free, however, even though the Gel batteries have a better life span, AGM batteries have a better energy density, can discharge more easily and are 20% smaller than the Gel batteries. All of which make the AGM batteries more popular for storage.

As a counterpart to Lead Acid Batteries, we can find Lithium-ion Batteries. These are not as widely used due to its very high cost. However, from a performance, DoD and life span standpoint, lithium ion batteries are in all aspects way better than Lead-Acid.

The following table shows an in-depth comparison of both types of batteries:

Parameter	Lithium ion	VRLA AGM	VRLA Gel
Energy Density (Wh/l)	250	100	80
Maintenance	No	No	No
Initial Cost (U$S/kWh)	600	120	65
Life Cycle	1900	500	600-800
DoD	80-90%	50%	50%
Thermal Sensitivity	Degrades above 45°C	Degrades above 25°C	Degrades above 25°C
Efficiency	100% @ 20hr rate	100% @ 20hr rate	100% @ 20hr rate
	99% @ 4hr rate	80% @ 4hr rate	80% @ 4hr rate
	92% @1 hr rate	60% @1 hr rate	60% @1 hr rate

Table 1 Comparison between different batteries

1.1.5. Inverter

The inverter is necessary in order to convert DC current to AC current. It can also be used to regulate the output voltage and to modulate the alternative output wave.

The following aspects must be taken into account when selecting an inverter:

- The input voltage and current must be in accord to the supplied by the generator.
- The maximum output/input power.
- Output voltage and current.

According to the output characteristics, there are three types of inverter:

- Square wave:
    - Simplest and most economic inverter type.
    - The output is not pure AC, as instead of resulting in a sine wave, it results in a square wave.
    - It's the least use as most appliances are designed for a sine wave supply. The supply of a square wave can damage the appliances.
- Modified wave:
    - Its construction is a bit more complex than a square wave but way more simple than a pure sinusoidal wave.
    - The resulting output is not as smooth as a pure sine wave.
- Sinusoidal Wave:
    - Its construction is the most complex of all inverter types.
    - The output is a pure sine wave.
    - Most effective and reliable.

Inverters can be directly connected to the Solar PV panels or to batteries, as would be the case in an autonomous system.

The efficiency of the inverter is directly related to the charge to which they are connected.

Figure 8 illustrates the correlation between the efficiency and the power factor.
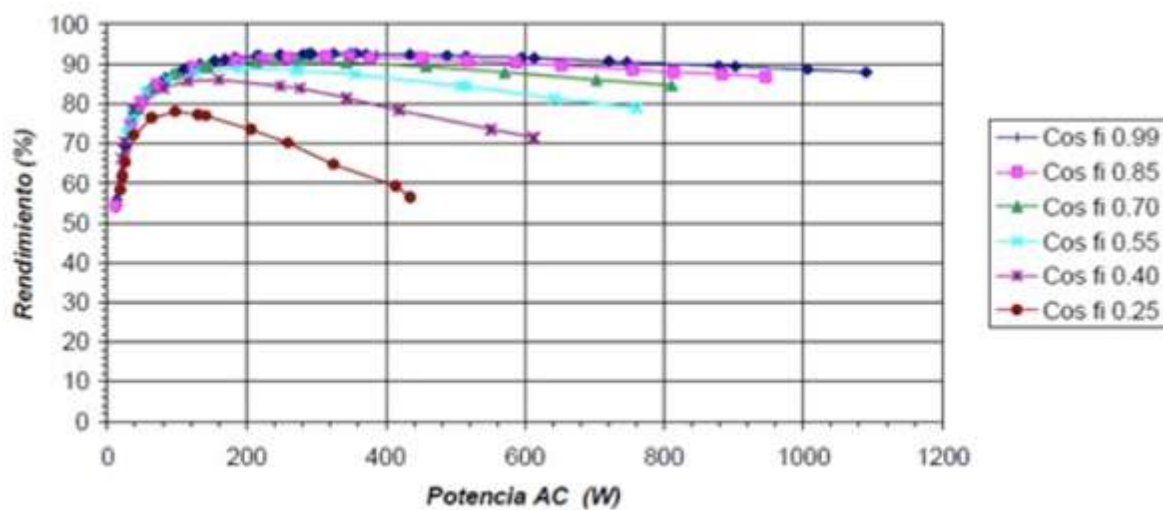
Figure 8 Correlation between efficiency and power factor, for different fi values.
Source: Moreno Martin 2016

Ultimately the normal layout of a Solar PV System is as follows:
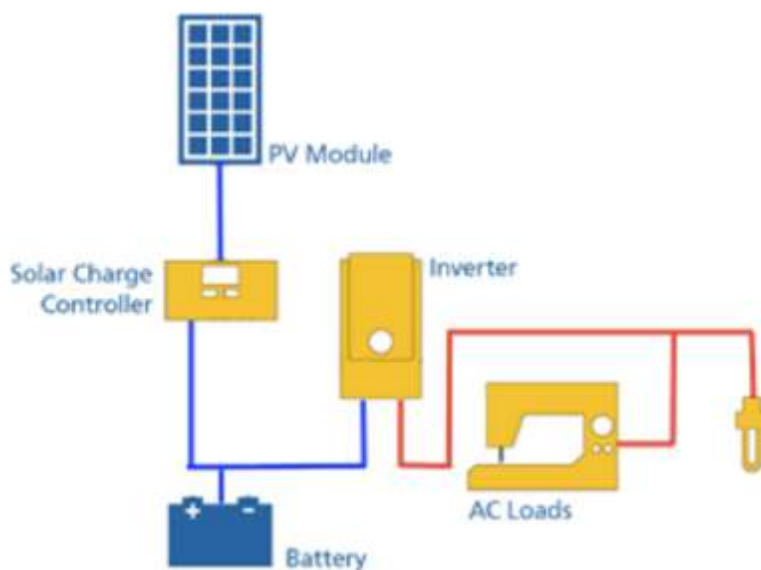
Figure 9 Typical layout of a Solar PV System.
Source: https://www.ruralelec.org/sites/default/files/are_technological_publication_0.pdf

All modern inverters have the Charge Controller or regulation system built-in, thus eliminating the need of including one in the design. This type of inverter is the one that will be used for the design of the Solar Boat.

Regulation systems are required for an optimal charging process of the batteries, thus achieving a full load without overcharging them by regulating the power supply to the batteries when these are near its limit. By avoiding any overcharging or overvoltage, the life cycle of the system is preserved.

Once the battery is fully loaded and no energy is being used by the applications, the inverter puts the solar PV panel on an open circuit, so that no more energy is produced. Due to this, the batteries are put on a floating mode.

Regulators also prevent the batteries to discharge below 30% when the sun is present (recommended for a AGM Lead-Acid battery).

1.1.6. Rectifier - SMPS

A rectifier is essentially the opposite to an inverter, it converts the AC current to DC current.

The process is known as rectification, since it "straightens" the direction of the current.

In order to achieve a higher efficiency a Switched-Mode Power Supply (SMPS) is recommended. This type of device incorporates a switching regulator to convert electrical power efficiently.

The SMPS transfers power from AC to DC or it can be used as a DC-DC converter, while converting voltage and current characteristics. It can regulate the voltage by varying the ratio of on-to-off time dissipating less energy, hence improving efficiency.

It should also be stated that the size is smaller than a linear rectifier, the noise is lower and eliminates the need for heavy line-frequency transformer. In counterpart SMPS require a much complex circuit than a linear rectifier.

Figure 10 illustrates a block diagram of a normal SMPS.
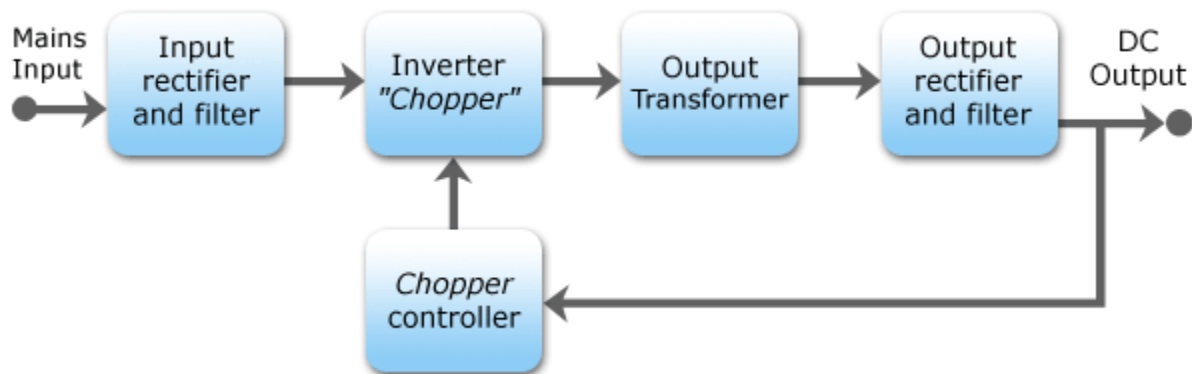
Figure 10 Block Diagram of a AC/DC SMPS with output voltage regulation.
Source: Wikipedia

Rectifier circuits may be single-phase or multi-phase. Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC.

For the purpose of the project, the rectifiers needed on the SMPS are of low power requirements, so single-phase rectifiers were selected.

There are mainly two types of single-phase rectifiers:

- Half-wave rectification: either the positive or negative half of the AC wave is passed, while the other half is blocked.
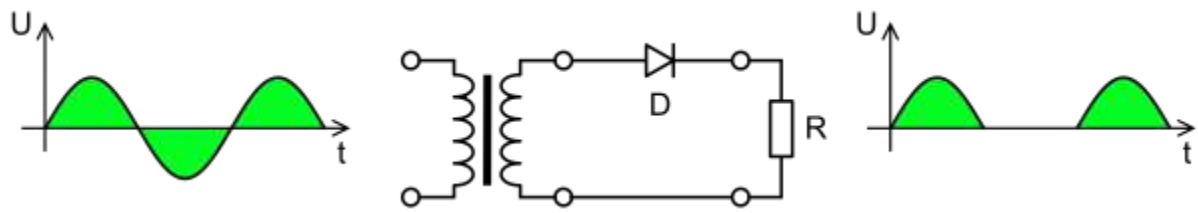
Figure 11 Half-wave rectification.
Source: Wikipedia.

- Full Wave Rectification: converts the whole of the input waveform to one of constant polarity (positive or negative) at its output.
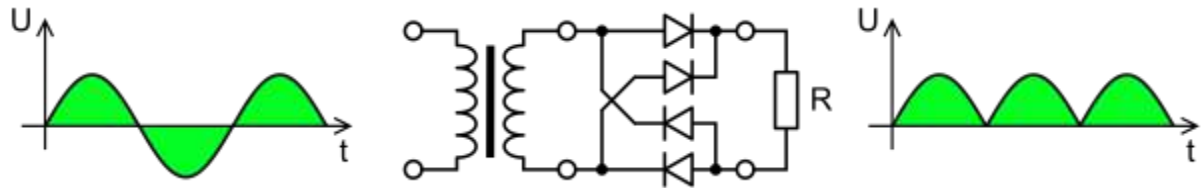
Figure 12 Full Wave Rectification using four diodes.
Source: Wikipedia

1.2. Method to Design a PV Solar Project

The objective of the chosen method is to ensure that the project will not be oversized, hence avoiding unnecessary costs.

The design of the project will cover all aspects ranging from the amount of chosen solar panels, the inclusion of electronic elements such as inverters and rectifiers in order to guarantee the functionality of the system to the design of the battery storage to achieve the maximum autonomy.

This method takes into account the following opposite scenarios:

- Normal day with normal sun exposure.
- Maximum autonomy scenario with a long period of time with no sun shining on the panels.

For the last scenario, the main applications that must powered must be identified so as to ensure their availability during the worst case scenario. Here is where the battery storage design plays a key role.

The following calculations must be made in order to guarantee a correct design:

1. Calculate the individual power of each application. It is important to know the voltage and power requirements for each application.

2. Estimate the daily time-of-use rate of each application. It is also important to know approximately at which hour of the day the applications are used.

   It will prove useful and graphically advantageous to make a flowchart of hours vs power. This type of chart is called an Energy Flow Chart.

   Note: If different applications are used simultaneously, the power consumptions must be added in the chart.

3. Calculate maximum Energy Requirement. With the Energy Flow Chart, the energy requirement for each hour must be calculated based on the following formula:

$$E(kWh) = P(kW) * t(h)$$

4. Determine the maximum scenario. Identify the most critical applications and the period of time in which the plant must be working in order to guarantee the availability of these applications. Based on this, calculate the amount of energy required.

With the values obtained on points 3 and 4, the largest one must be used in order to design the necessary battery storage.

The design of the array of solar panels needed will also be determined by the amount of energy that needs to be stored taking into account the largest energy requirement calculated on points 3 and 4. The current and voltages required by the selected inverter will determine the type of connection (parallel/series) needed for the solar panels.

Finally, in order to correctly estimate the amount of solar panels needed, we must take into account the irradiation (kWh/m^2) value of the sun on the area in which the solar plant will be placed. With that value, alongside with the efficiency of the panels and the energy requirements, we will be able to determine the amount of m^2 of solar panels needed and in consequence, the amount of solar panels needed.

It is important to keep in mind that the irradiation value strongly depends on the station of the year, reaching its maximum values in summer and minimum values in winter. To accomplish a correct design one must select the winter values of irradiation.

1.3. Relevance of Solar PV Electricity in Argentina

Argentina's solar energy potential is very large, as shown in Figure 13.

As shown on Figure 13, Concordia has around 1,80-1,85 MWh/m^2year of solar irradiation. This value makes it optimal for solar energy.

For a more detailed analysis of Argentina's solar potential the "Guía del Recurso Solar" document provided by the Sub Secretary of Renewable Energies and Electric Efficiency of Argentina can be obtained online.

This document not only contains all the irradiation values for each Argentinian province throughout a year, but also includes inclination variable tables for different azimuth values.
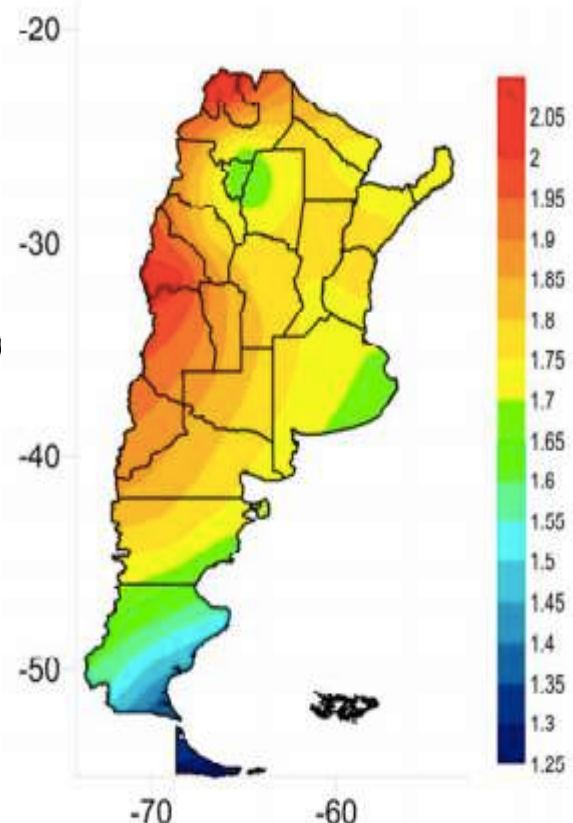
Figure 13 *Irradiation map of Argentina, scale on MWh/m^2 year adjusted on the most effective angle. Source: Righini et. Al.*

Another important aspect to consider is the amount of clear sky days in Concordia throughout the year. This value can be obtained directly from the INTA records.

According to INTA's data, see Figure 14, Concordia's average amount of hours of sunshine throughout an entire year is of 2543 h/year (or 6.97 h/day). Considering that a year contains around 4380 daylight hours in total (aprox. 12 hours per day), this means that Concordia has ideal conditions for solar energy almost 60% of the time.

So as to verify the information stated above, a simulation was performed in "SOLARGIS" using a 1,6kW Solar PV System with no inclination on the horizontal plane and even though the results show a much more accurate irradiance for Salto Grande, the overall results are very similar to the ones provided by official sources.

Figure 14 Average annual amount of days on complete sun on Argentina.
Source: http://foro.gustfront.com.ar/viewtopic.php?t=3186
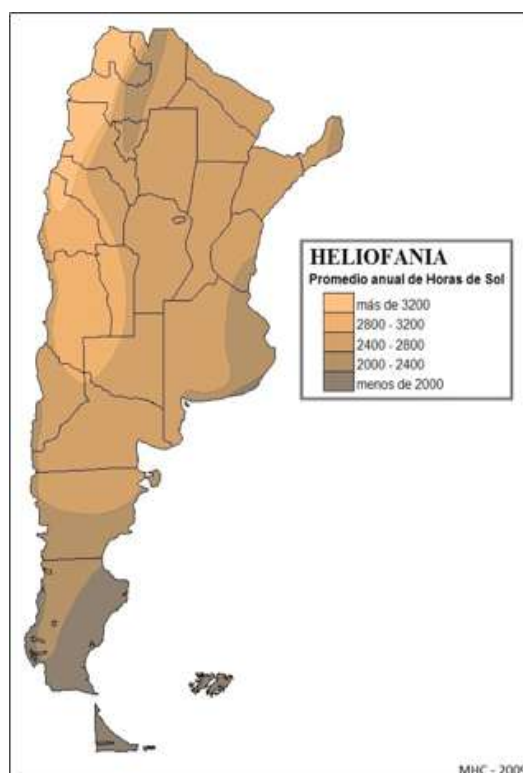
Figure 15 shows only the irradiation section of the simulation; the entire results of the simulation can be found on the Annex 1.

Month	Gh$_m$	Gh$_d$	Dh$_d$	T$_{24}$
Jan	228	7.34	2.09	27.2
Feb	177	6.30	2.01	25.7
Mar	166	5.35	1.70	23.5
Apr	121	4.04	1.29	18.7
May	95	3.06	1.16	14.8
Jun	75	2.50	0.98	12.5
Jul	90	2.90	1.06	11.7
Aug	113	3.65	1.37	14.2
Sep	139	4.65	1.66	15.6
Oct	174	5.61	1.90	19.0
Nov	207	6.90	1.95	21.6
Dec	224	7.21	2.11	25.0
Year	1808	4.95	1.60	19.1

Long-term monthly averages:

Gh$_m$ Monthly sum of global irradiation [kWh/m^2]
Gh$_d$ Daily sum of global irradiation [kWh/m^2]
Dh$_d$ Daily sum of diffuse irradiation [kWh/m^2]
T$_{24}$ Daily (diurnal) air temperature [°C]

Figure 15 Results of the Simulation using SOLARGIS.

According to the simulation, the total irradiance for Salto Grande is around 1808 kWh/m^2, being the lower value 2.5 kWh/m^2 for a day in June.

Based on this information, it is no surprise that the past November the RECAI (Renewable Energy Country Attractiveness Index) placed Argentina on the top 10 list for countries with high potential for renewable energy development.

However, even though Argentina's Secretary of Energy projects that by 2025 the country will have up to 2 GW of installed solar energy, there are currently no plans for a renewable energy power plant in the province of Entre Rios, where the city of Concordia resides.

1.4. Environmental Situation at Salto Grande Dam Reservoir

The principal environmental threat to the reservoir of Salto Grande is eutrophication. Eutrophication is produced by an excess of nutrients (mainly nitrogen and phosphorous) and organic matter in the water. The principal cause of the accumulation of these nutrients is the dam itself, as it concentrates untreated sewage waste and industrial water from treatment plants.

This phenomenon is aggravated during the summer season where it leads to the appearance of algae blooms.

The presence of algae in water brings different problems to the water quality. The most important being:

- Foam forming and disgusting smells. This modifies the taste of the water and its color, giving it a greenish shade.

- The decomposition process causes a deoxygenating water environment which alters the water chemistry and affects the survival of fish and water organisms. It also causes negative effects on:
    - o Recreational water usage.
    - o Process used by potabilization plants in order to treat this water.
    - o Release of toxins into the water.

This is a recurrent problem for the reservoir at Salto Grande. Over the last few years several recreation centers have been temporarily shut down due to eutrophication.

There are several techniques to tackle this problem, such as oxygenation and sedimentation ponds, these however require a big amount of energy or the use of expensive and contaminant chemicals.

Nevertheless, there are alternative methods such as Electro Coagulation and High Frequency Ultrasound that require much less energy or the use of expensive chemicals.

High frequency ultrasound is mainly used to eliminate algae blooms and reduce the turbidity and chlorophyll A on water. Two problems present on the Salto Grande Dam. The energy required by the ultrasound can be easily obtained by solar photovoltaic panels and is an ideal treatment method to locate on the boat.

1.4.1. Algae Concentration on Salto Grande Dam

On 2015, CARU (Comisión Administradora del Río Uruguay) conducted a study to research the places where nutrients and Chlorophyll A are more likely to deposit themselves in the dam. This study is useful as algae blooms are more likely to appear near these deposits.

The images in Figures 16-18 show the concentration of Chlorophyll on different ramifications, near the Salto Grande Dam.
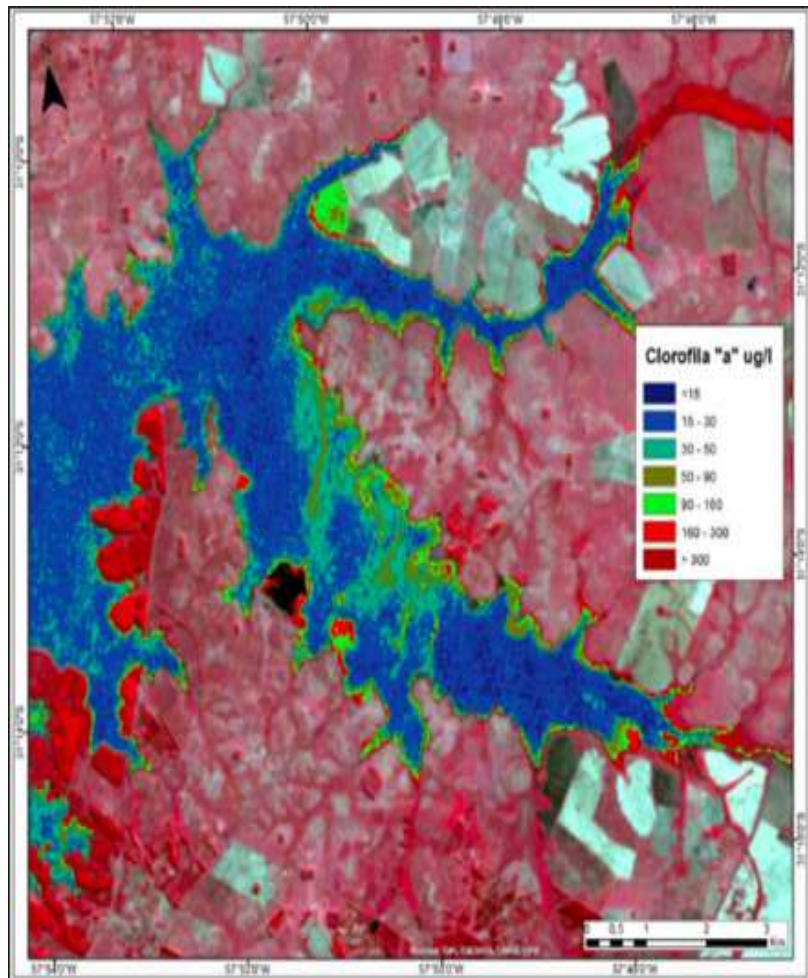
Figure 16 Itapebi ramification.
Source: CARU
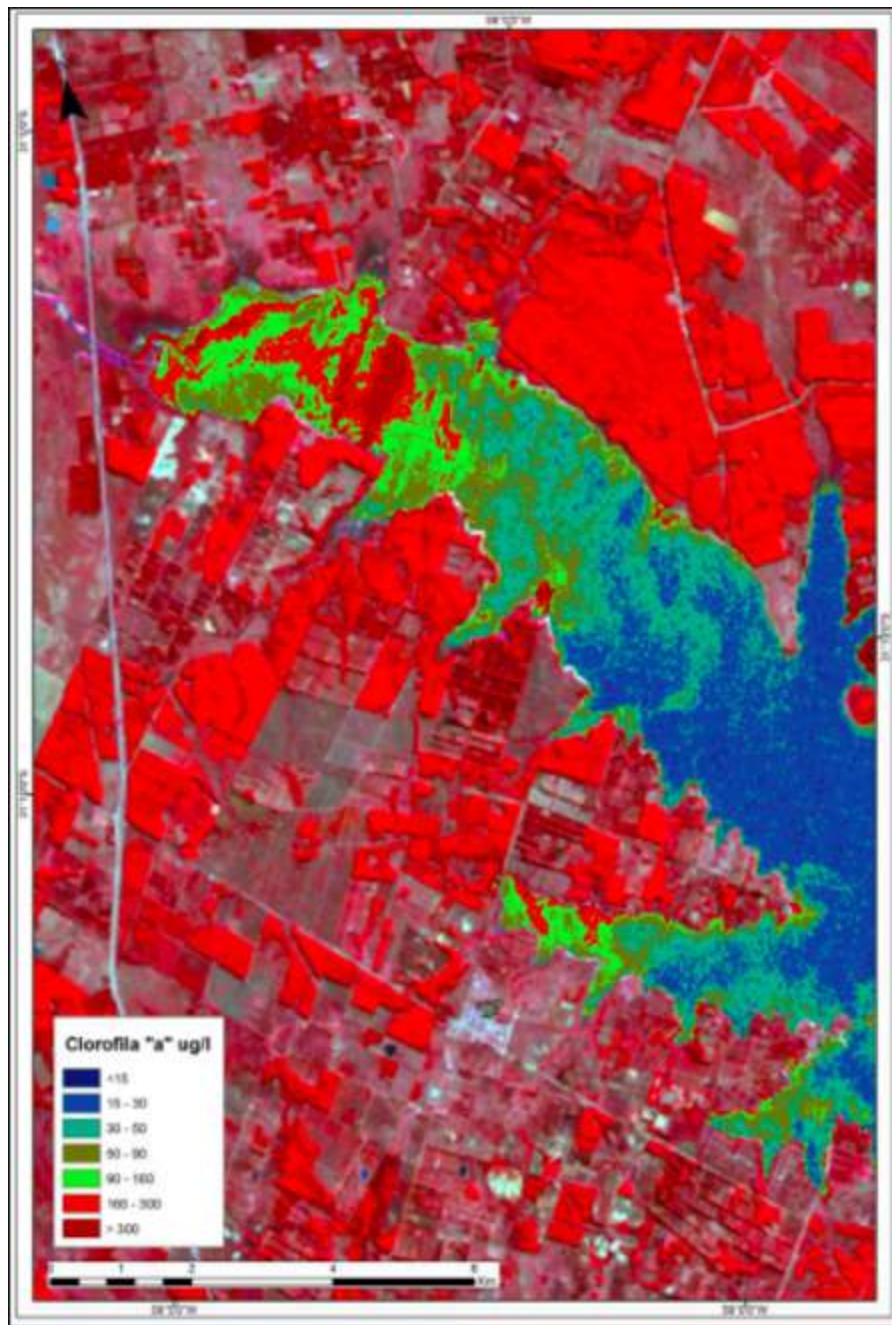
Figure 17 Gualeguaycito ramification.
Source: CARU
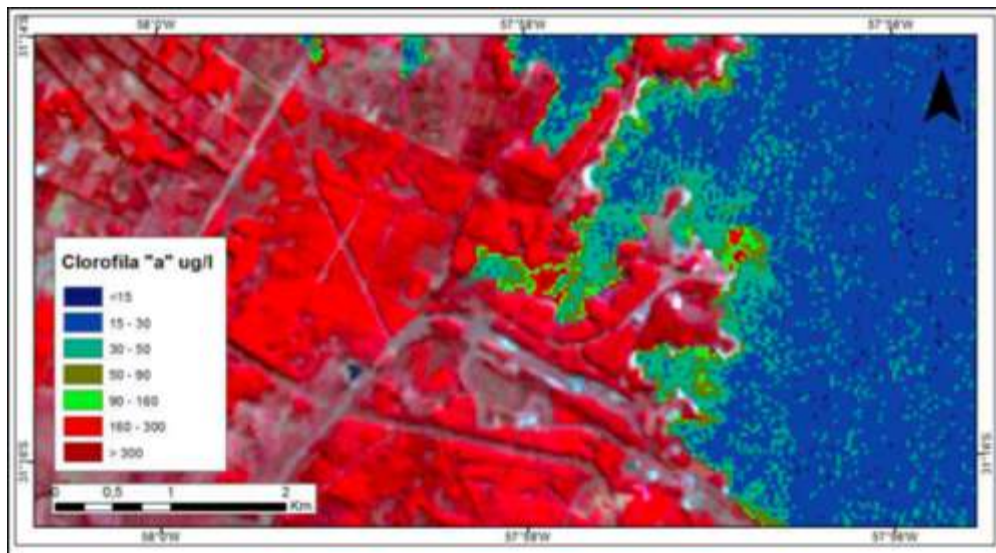
Figure 18 Puerto Luis.
Source: CARU

The image in Figure 19 shows the reservoir phosphorus concentration
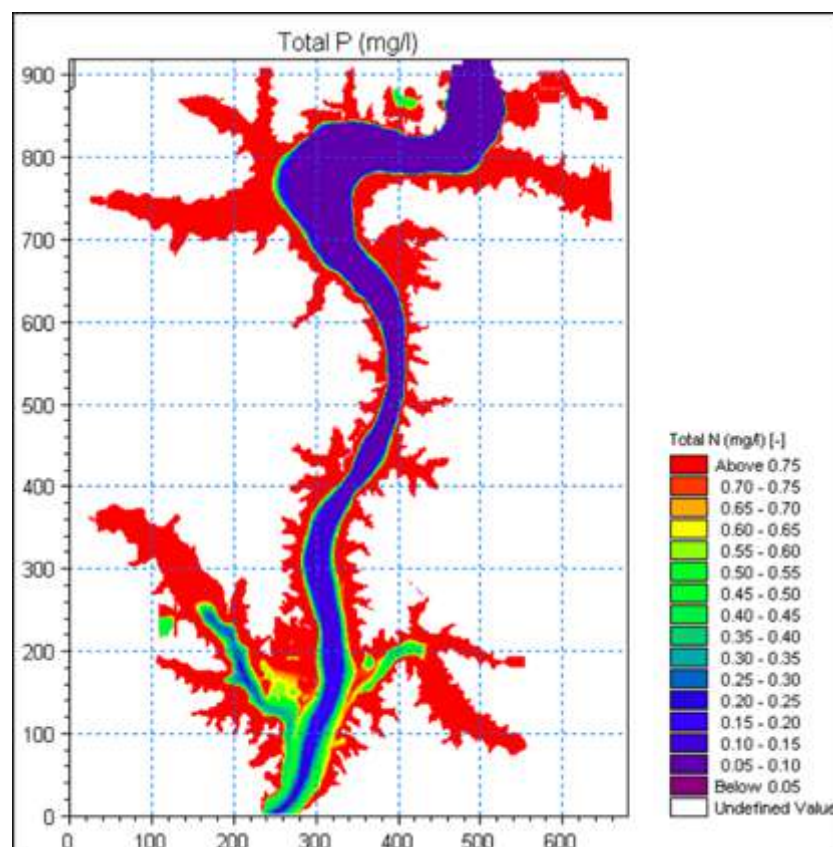
Figure 19 Phosphorus concentration on the Salto Grande Reservoir.
Source: CARU

Other nutrients needed for an algae bloom, such as nitrogen and potassium, can be also assumed to be at a higher concentration near the same places where the phosphorus concentration is high.

1.4.2. Environmental Analysis of the Floatable Displaceable Solar Power Plant

There are several environmental aspects that must be taken into account when assessing the impact of the boat on the reservoir dam. These are:

- Eutrophication
- Evaporation
- Shading on large surfaces
- Noise pollution
- Leakage

1.4.2.1. Eutrophication

The eutrophication occurs by the excess presence of nutrients and organic matter. When exposed to direct sunlight, this produces the algae bloom. Once the nutrients start to decrease, the algae start to die, thus releasing both bad toxins into the water and unpleasant smells into the environment.

Because the boat floats on the surface, it can prevent some sunlight from reaching the organic matter and reduce the amount of algae. However, since for this project the surface covered is significantly smaller compared to the surface of the reservoir, the overall impact is quite small.

1.4.2.2. Evaporation

Evaporation of water, specially on a big reservoir such as Salto Grande's, can cause a microclimate on the nearby environment. This microclimate can modify the fauna and the flora of the region. This effect is aggravated by the size of the reservoir, having more impact the bigger the size of of the reservoir.

Having said this, covering part of the reservoir surface with solar panels can cause a positive impact on the region, however since for this project, the covered surface is significantly smaller than the surface of the reservoir, the overall impact is also quite small.

1.4.2.3. Shading of Large Surfaces

This shading of necessary sunlight can prevent photosynthesis in aquatic plants from happening. This will affect the development of the plants and directly affect the fishes that feed off them. This can cause a chain of events that might result on a lower amount of fish on the reservoir.

Once again it is important to keep in mind that the covered surface is significantly smaller compared to the surface of the reservoir, so the overall impact is quite small. Also, since the boat will be constantly moving, it will never be placed on the same spot for long periods of time.

1.4.2.4. Noise Pollution

The solar boat will be propelled by a PMSM motor (the selection of this motor will be explained on the section 2.5). One of the big advantages of this type of motor is that compared to a normal boat engine, the noise produced by the PMSM engine is significantly lower, resulting in a smaller environmental impact to the fauna.

1.4.2.5. Leakage

Normally boats require a fossil fuel to propel the engine, but the solar boat will use the sun as a mean to power the engine. Having fossil fuels on board is a leaking hazard that will be avoided, hence resulting on a healthier environment for the flora and fauna of the reservoir.

1.5. Water Quality at Salto Grande Reservoir

According to the Salto Grande Environmental Plan, from the months of December to April since 2007, samples have been taken weekly from 30 different stations located on the reservoir and waters down the dam. During the rest of the year, the sampling is done on monthly basis.

The parameters analyzed are Chlorophyll A, Algae density, Dissolved Oxygen, Saturation Percentage, pH, Conductivity, Temperature, Turbidity, Microcystin and E coli, so as to be able to approve the use of the water for recreational purposes or as beach under the standards established by the WHO (World Health Organization).

These values are tested by the Comisión Administradora del Río Uruguay (CARU).

The following 4 stations from the reservoir where selected for the purpose of this project in order to analyze and compare the collected samples.

Figure 20 Beaches Tested by CARU near the Salto Grande Dam.
Source: Google Earth.

For the specific case on algae bloom, levels of Chlorophyll A, Microcystin and Cyanobacteria are measured and depending on the values, different level of awareness is defined.

Levels of Awareness:

Vigilance	Alert 1	Alert 2
<10 g/l Chlorophyll A	10 - 50 g/l Chlorophyll A	>50 g/l Chlorophyll A
<5.000 cells/ml cyanobacteria or absence of cluster	5.000 – 50.0000 cells/ml cyanobacteria or absence of cluster	>50.000 cells/ml cyanobacteria or presence of cluster
<2 g/l microcystin	2 - 10 g/l microcystin	>10 g/l microcystin

Table 2 Levels of Awareness by Sampled Parameters on the Beaches near the Salto Grande Dam

Table 3 shows the values sampled from February to April of 2019

Date	Sample Point	E. Coli (UFC/100 ml)	Fecal Coliforms (UFC/100 ml)	Enterococcus (UFC/100 ml)	Algae Bloom
6/3/19	Parque del Lago	232	200	240	Vigilance
11/3/19		20	10	130	Vigilance
18/3/19		28	10	435	Vigilance
25/3/19		640	240	3220	Alert 1
8/4/19		53	40	290	Vigilance
6/3/19	La Toma	150	176	100	Vigilance
11/3/19		10	26	120	Vigilance
18/3/19		10	30	60	Vigilance
25/3/19		90	1988	5500	Vigilance
8/4/19		40	54	45	Vigilance
6/3/19	Las Palmeras	392	310	600	Alert 1
11/3/19		178	40	1650	Alert 1
18/3/19		26	20	1680	Vigilance
25/3/19		670	300	3500	Alert 1
8/4/19		62	40	205	Alert 1
6/3/19	Sol	160	208	230	Vigilance
11/3/19		40	120	135	Alert 1
18/3/19		40	50	50	Vigilance
25/3/19		120	320	2400	Vigilance
8/4/19		<1	<1	205	Alert 1

Table 3 Values Sampled by CARU on the beaches selected nearby the Salto Grande Dam

Between the months of December to April algae blooms on the reservoir of Salto Grande are higher than the rest of the year, making the use of the water for recreational purposes during these months unacceptable.

Finally, besides from all the previously stated problems, Salto Grande Reservoir suffers from pollution due to nearby industries that dump their treatment water directly into the Uruguay

River and also from pesticides used on the fields that end up in the reservoir after being absorbed into the underground runoff.

A study conducted by Montti, María et. Al., from the year 2012 to 2016, shows a level of contamination by pesticides on water and soil near the Salto Grande Reservoir that, in some cases, are even higher than the acceptable levels that the Argentinean law for Danger Residues N° 24051, recommends for potabilization plants. This is a major issue that must be addressed and solved by other means.

1.6. Floating Solar PV Around the World

The implementation of solar PV projects has significantly grown over the past few years. Furthermore, according to the World Bank, by 2018 the global capacity of floating solar PV had reached up to 1.1 GW, being Asia the leader in the market.

Table 4 lists the top 10 floating solar power plants in the world:

Location	Capacity (kW)	Country
Coal Mining Subsidence area of Huainan City	40,000	China
Coal Mining Subsidence area of Huainan City	20,000	China
Yamakura Solar Power Plant	13,700	Japan
Pei Country	9,982	China
Umenoki	7,550	Japan
Jining GCL	6,776	China
Hirotani Ike Floating Solar Plant	6,800	Japan
Queen Elizabeth II Reservoir	6,338	UK
Cheongpung Lake	3,000	South Korea
Otae Province	3,000	South Korea

Table 4 List of top 10 Floating Solar Power Plants.
Source: Solar Asset Management Asia

This list will be significantly improved when the 102.5 MW project in South Korea is finished, around 2020, on Sihwa Lake.

The cumulative capacity of all plants around the world adds up to 246 MW, and more than 50% is located in Japan. The other top leaders are China, South Korea, UK and Taiwan. See Figures 21-22.

Figure 21 Image of the Design of the Floating Solar PV in Sihwa Lake, South Korea.
Source: http://english.hani.co.kr/arti/english_edition/e_business/860644.html
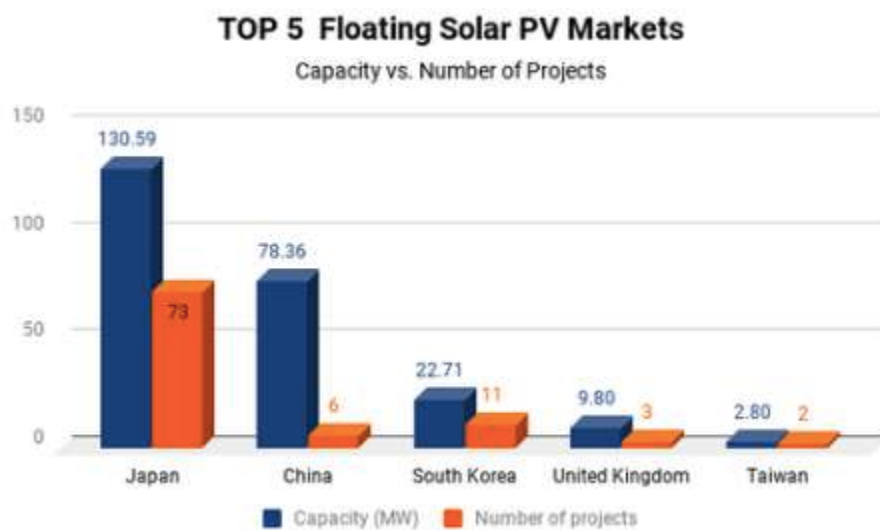
Figure 22 Top 5 Floating Solar PV markets.
Source: Solar Asset Management Asia.

There are a lot of reasons why floating solar PV projects are so popular:

- Converts underutilized bodies of water into power plants.

- Presents zero cost when it comes to land acquisition.

- Increased output and operational efficiency as a result of the water inherent cooling nature when evaporated.

- Reduces Algae growth.

- Improves the Plant Load Factor due to the lack of tracking system.

There are however some concerns regarding this type of plant, such as:

- The evaporating water can create fog that might result in the reduction of the light on the solar panels.

- The panels life span might be reduced due to the saltiness of the water.

- Since the panels are not attached to the ground, some of them might be damaged by strong winds and currents.

1.6.1.   Floating Solar PV Plants in South America

Brazil has just unveiled its first stage of a Floating Solar PV Plant plant in the Bahia State, on the Hydroelectric plant of Sobradinho. See Figure 23. It consists of a 1 MW peak project and is planned to be updated to 2.5 MW by 2020.

Figure 23 Sobradinho Floating Solar PV Plant.
Source: Revista Pesquisa

Another small scale plant was installed in Chile, on top of a Mining Storage Tank in Paine, consisting of 256 solar PV panels installed.

2. Applications of the Floating PV Plant

1. Introduction to the Project
2. Monitoring of the water quality of the reservoir
3. Water treatment by electrocoagulation
4. Algae Treatment by high frequency ultrasound
5. Solar Mobility of the Floating Solar Power Plant
6. Water Pumping
7. Battery Bank for Solar Energy Storage

2.1. Introduction to the Project

This project focuses on the generation of electrical energy through solar PV panels, but most importantly, on the possible environmental and social uses and applications of the solar energy besides the electrical energy produced.

In order to achieve a higher environmental and social impact, the applications must be available where needed. To achieve this, the solar plant must be able to move around the Salto Grande reservoir.

Another interesting goal of this project is for it to be used as a capacitation center for people that wish to learn more about solar PV energy, ranging from the design of a system to the multiple applications of solar PV energy.

In order to move along the reservoir, the solar plant must be placed on top of a Boat. The Boat will have all the appliances (solar panels, batteries, inverters, rectifiers, etc.) necessaries to make all the applications work.

For the Salto Grande Dam, the following applications can be achieved:

1. Monitoring of the Water Quality of the Reservoir.

2. Water Treatment by Electro-Coagulation.

3. Alga Treatment by Ultrasound.

4. Solar Mobility of the Floating Solar Power Plant.

5. Water Pumping for all needs.

Each application will be discussed on further on this section.

Furthermore, the boat could also be used for recreational purposes such as tours around the reservoir or as another source of energy for other devices near the boat.

2.2. Monitoring of the Water Quality of the Reservoir

The dam at Salto Grande has an environmental assessment plan in place for the monitoring of the water quality near the dam.

Multiple samples are taken and later analyzed so as to measure different physical and chemical parameters, such as:

- Conductivity
- pH
- Dissolved Oxygen
- Total Dissolved Solids
- Temperature

The multiple measuring probes necessary for this assessment can demand a voltage up to 12V DC. These power demands make them ideal to operate with solar power.

The following probes can be used for this activity:

- REDOX Sensor
- Dissolved Oxygen Sensor
- Electric Conductivity/ Salinity/ Total Dissolved Solids Sensor
- pH / Temperature Sensor

All probes must be connected to a monitoring machine that will periodically store its measurements. The frequency of which the measurements will be stored can be adapted according to the study needs.

The recollected data is later sent to a remote server through GSM, which will allow us to have Automatic Water Quality Indicators on the Dam, a goal imposed by the Environmental Plan of the Salto Grande Dam in 2017.

This environmental plan requests the measurement of the following parameters:

	Parameter	Media
Physical	Conductivity, pH, Turbidity, Total Solids	Water
Chemical	'A' Chlorophyll, Total Nitrogen, Total Phosphorus and fractions, agrochemicals, Hydrocarbons, Mercury, Lead, Chrome V and Methyl-Mercury.	Water / Sediment
Biological	E-coli, Phytoplankton, Thermotolerant Coliforms, Enterococcus and Heterotrophs.	Water

Table 5 Physical, Chemical and Biological parameters measured on the Salto Grande Reservoir per the Environmental Plan

Because all probes must be connected to the monitoring machine, only the latter needs to be powered. The technical details of all probes and the monitoring machine will be discussed on section 3.1.

2.3. Water Treatment by Electrocoagulation

An Electrocoagulation process involves an electrolysis followed by a coagulation of the pollutants. Electrolysis is the process where, on water or a salty solution, ions are exchanged between two electrodes when an electric current is applied. The positive atoms will move to the cathode while the negative atoms to the anode, resulting in the dissolution of the anode.
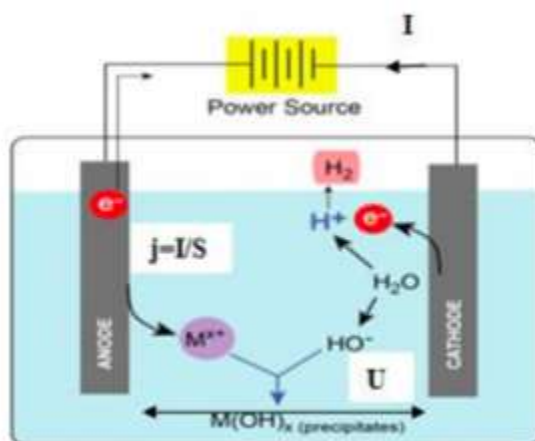
Figure 24 EC Cell
, where M is the metal, x is the oxidation state, I is current, U is cell potential, j is current density and S is the Surface area of the anode. Source: Azarian et.Al

Typically, potabilization plants use the flocculation-coagulation process in order to treat the water and eliminate contaminants. However, in order to do so it must introduce chemicals into the process.

As an alternative to this, the Electrocoagulation process can be used in a potabilization plant so as to achieve the same result without having to introduce any chemicals into the water. This process uses instead a sacrificial anode, mainly made of Aluminum or Iron, that will be reduced to form either $Al(OH)_2$ (Aluminum Hydroxide) or $Fe(OH)_2$ (Iron Hydroxide).

During the electrolysis the material from the anode will create the coagulation ions. These ions will undergo hydrolysis in water forming the metallic coagulant species mentioned above.

The main mechanism in which the pollutants are removed from the water is through the absorption on the metal hydroxide formed.

The amount of coagulant species released from the anode follows Faraday's law:

$$m = I * t * M * F$$

, where I is the current (A), t is time of operation (s), M is the molecular weight of the anode material (g/mol), F is the Faraday constant (96,485 C/mol), z is the number of electrons involved in the reaction and m is the mass of anode that dissolves.

During the electrolysis, the water involved will produce hydrogen bubbles:

$$2\,H_2O + 2e^- \leftrightarrow H_2(g) + 2OH^-$$
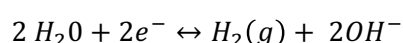
These hydrogen bubbles will float to the surface and will induce the pollutants to float towards the surface, making it easier to remove them. The hydroxides produced will later combine with the metal dissolved from the anode and produce the flocculant agent.

The main advantages of Electrocoagulation are:

- Much more effective at removing contaminants than more conventional methods

- Requires simple equipment and is simple to operate

- Has no moving parts

- It's low maintenance

- Generates low sludge formation, mainly composed by metal hydroxides that are simple to dewater

- Flocs formed are larger than those in conventional methods and contain less water in them

- Does not require the use of chemicals

- Gas bubbles produced by the electrolysis (H_2) produce a flotation of the pollutants, which facilitates their separation

- EC requires small electrical input, so the usage of renewable energy, in this case solar energy, it is a perfect fit

- Requires a smaller batch compared to more conventional methods

This type of water treatment can be used to treat different pollutants, from chlorophyll A to Arsenic, to different degree of effectiveness, depending on the type of anode used. Normally, due to cost-effective analysis, the anodes used are Aluminum or Iron.

When designing a water treatment process, different factors must be taken into account in order to achieve a maximum efficiency:

- Electrode arrangement, material, shape and distance

- Pollutant concentration

- Current density

- Initial pH

- Electrolysis time

All these parameters are discussed on the Section 3.2 Water Treatment by Electrocoagulation.

Finally, another important aspect to consider in the design is the type of plant. There are two main types: continuous and batch design.

The batch design consists on a wide tank filled with water to treat that after a period of time, must be emptied and loaded again to allow the treatment to proceed. The continuous design, on the other hand allows a continuous flow of water constantly entering and leaving the tank.

This type of design is the most popular in water treatment plants, since it can treat a larger amount of water compared to a batch design. It also enhances the efficiency of the flocculation since it prevents the flocs from attaching to the electrodes.
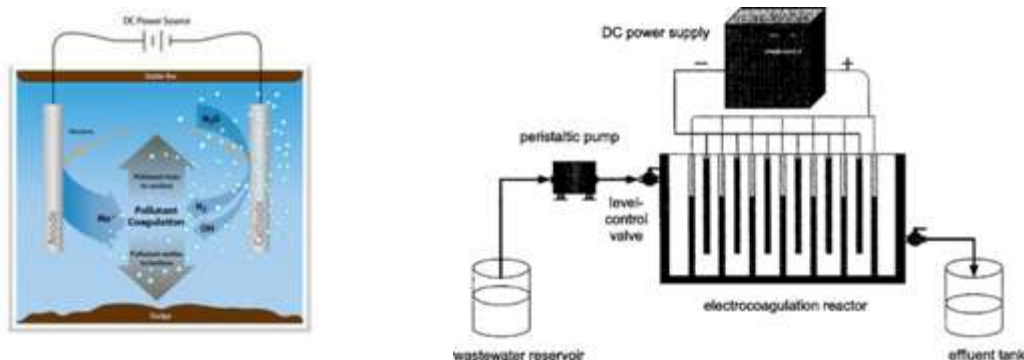
Figure 25 On the right, a batch design of electrocoagulation; on the left, a continuous design of electrocoagulation. Source: Den et.Al.

It is important to keep in mind that a treatment performed solely by Electrocoagulation might not comply with drinkable water regulations. Depending on the water quality, a secondary treatment such as sedimentation of filtration might be needed in order to complete its treatment.

For the specific case of waste/oily water an activated carbon filter is used; and for arsenic on groundwater an anodic oxidation system can be used to achieve a removal efficiency of around 100%.

For the prototype for Salto Grande, the continuous mode type was chosen since it needs a water pump to work which can be powered by solar power, hence giving another application for the solar power plant.

On a bigger scale, beyond Salto Grande, this prototype treatment plant can be used to study the treatment of arsenic on groundwater supplies. A major problem that the Province of La Pampa currently has.

Conclusion

The treatment of water by electrocoagulation is perfectly complemented by the usage of solar panels to provide the energy to the pumping mechanism.

This prototype can be used to supply drinking water to secluded places where no service water is installed nor any connection to electrical grid is available and only underground water is accessible.

2.4. Algae Treatment by Ultrasound

This method consists on using a high frequency ultrasound to make the algae bloom sink under the surface. The phenomenon is possible due to the fact that the frequency emitted coincides with the natural resonance frequency of the cyanobacteria cellular walls of the gas vacuole, which as a consequence prevents them from keeping afloat.

The main advantage of this kind of algae treatment is that the cyanobacteria does not recognize that they are being treated and do not release any toxins into the water.

It is important to remark that the place of the reservoir where cyanobacteria sinks should be deep enough in order to prevent the light from reaching it, and thus preventing photosynthesis from taking place.

Figure 26 How the ultrasound works to control algae.
1: Ultrasound creates a sound layer on the top of the reservoir. 2: The ultrasound affects the buoyancy of the algae, fixing them in the water column. 3: Due to lack of nutrients and sunlight, the algae will die and sink to the bottom of the reservoir. 4: The algae are degraded by the bacteria. Source: LG Sonic

This kind of treatment can be also used to reduce the amount of chlorophyll A on the reservoir.

Besides from not using any kind of chemicals to eliminate the cyanobacteria, the frequency emitted does not cause harm to any kind of aquatic organism or plants. Unlike a study performed by Zimba & Grimm in 2008 that proved that catfish would not feed when induced to a high frequency ultrasound.

Another study made by Oyib, showed that on lakes where ultrasound is used to control cyanobacteria, a heavier fish yield was found. This was because a healthier environment and water quality produced a better use of the nutrients on water, causing heavier fish.

Different cyanobacteria have a different natural resonance frequency, so it is important to determine which type of cyanobacteria are in the reservoir, in order to adjust the frequency of the ultrasound.

There are however some types of cyanobacteria that present a resistance to this type of treatment, such is the case for the Chara, Pithophora, Rock Snot, Rhizoclonium, Oscillitoria and Nitella. On the Salto Grande reservoir, the type of cyanobacteria present is Microcystis

aeruginosa. This type of cyanobacteria can be treated effectively by high frequency ultrasound.

It is important to remark that this treatment is not a short term solution to the algae, being the average time necessary for the treatment to start giving results between 3 to 4 weeks.

Figure 27 is an ultrasound equipment can be powered by solar energy.

Figure 27 Image of the Ultrasonic Device.
Source: LG Sonic

As stated on section 1.5, the largest amount of nutrients and chlorophyll A are located on the ramifications of the Salto Grande reservoir. Because of this, these places are the most probable to have algae blooms.

Taking this into consideration, the boat must be able to reach the following locations, shown on Figure 28, in order to be in range to treat with the ultrasound.

Figure 28 Possible locations of the Solar Raft to treat the algae bloom present on the Salto Grande Reservoir

Conclusion:

The treatment of algae blooms using high frequency ultrasound is a tested technology with high effectiveness rate. Due to its low energy requirements it is perfect to supply such energy with solar energy.

It is important that the boat stays on these locations for a long period of time so as to achieve a complete removal of algae and achieve visible results within the first week

2.5. Solar Mobility of the Floating Solar Power Plant

One of the key aspects of the project is the ability of movement of the Solar Power Plant. In order to achieve this purpose an engine is needed. This engine must be big enough to allow the Solar Power Plant to move at a steady but slow rate, approximately 4 knots (7,4 km/h).

The selected engine for the purpose of the project was a Permanent Magnet Synchronous Motor (PMSM).

Table 6 compares this type of motor with a DC and induction motor:

PSMS over DC Motor	PSMS over Induction Motor
Less Audible Noise	Higher Efficiency
Sparkles	Higher Power Factor
Higher Rotation Speed	Higher Power Density for Lower than 10 kW applications, resulting on smaller size
High Power Density and Smaller Size	Better Heat Transfer
Better Heat Transfer, Higher Efficiency	-

Table 6 Advantages of PSMS over DC Motors and Induction Motors

Figure 29 Permanent Magnet Synchronous Motor.
Source: Volcano Electric

To achieve a correct estimation of the necessary boat size after selecting the motor, a table that considers the overall weight of the boat, engine power and speed is used.

Considering that the selected speed is 4 knots and that the selected engine is a PMSM 1HP motor, according to the Figure 30, the maximum weight of the boat can be up to 2 tons.
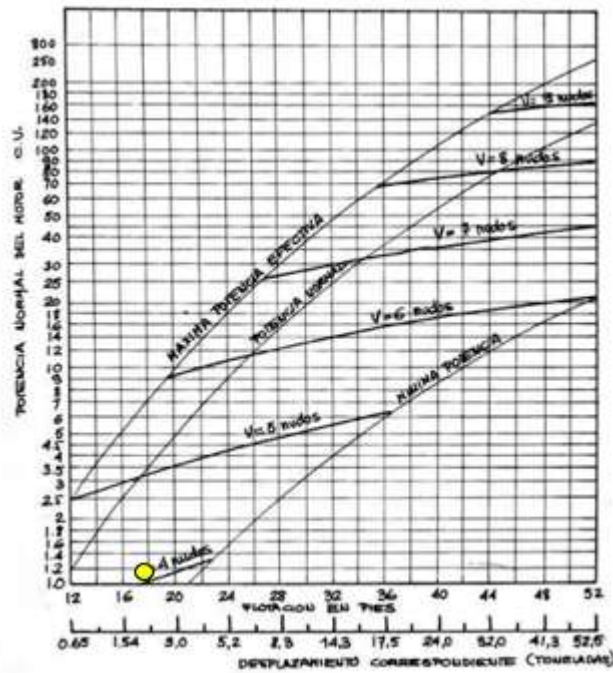
Figure 30 Engine Power (Y axis) in HP, vs Flotation (X axis) in tons.
On the graph isolines of same speed. On the graph the operation point (in yellow) can be seen for the selected engine and desired speed. Source: www.maniobradebuques.com

This motor will allow the boat to move at a constant speed while allowing for safe and enjoyable rides along the reservoir of Salto Grande. Figure 31 illustrates the area that can be covered by the boat:

Figure 31 Area covered by the Floating Solar Power Plant on the Salto Grande Reservoir.
On blue the area that can be covered by the boat, and on white possible roads that can be taken by the boat on a 2-hour trip (approximate 15km on every road).

In order to be able to locate the boat at all times, a GPS system will be added. This tracking system will also allow us to know where the water quality is being tested.

Conclusion

The PSMS motor allows for a more efficient and less audible option which can be powered by solar energy and an array of batteries. The array of batteries is needed to allow energy to be used during cloudy days or at night.

2.6. Water Pumping

One of the basic applications achievable by solar power is the pumping of water for different uses.

In the specific case of the Floating Solar Power Plant, pumping is needed for the EC Water Treatment Plant. This action can be accomplished by a small pump thanks to its low pumping height requirements.

The selection of the pump needed depends on the selected water flow and the height that the water needs to reach when being pumped.

Another use of the pump is to take water samples from different depths, as specified on the Environmental Plan of the Salto Grande Dam.

Finally, the pump can also be used to clean the solar panels.

Conclusion:

The pumping of water has a lot of different usages in the agricultural and, in this case, for the treatment of water by electrocoagulation. Because water does not need to be pumped so high and the flow is not so big, the pump selected will be a small one. This pump can be easily powered by solar energy.

3. Technical Proposal for the Prototype

On this section, the technical aspects of the applications described on Section 2 will be analyzed. The design of the PV system and recommendations for the boat will also be covered.

This section is divided as follows:

1. Monitoring of the Water Quality of the Reservoir
2. Water Treatment by Electrocoagulation
3. Algae Treatment by Ultrasound
4. Solar Mobility of the Floating Solar Power Plant
5. Water Pumping
6. Solar PV Design
7. Solar PV Boat Design

3.1. Monitoring of the Water Quality of the Reservoir

The water quality parameters that can be measured on site and in a continuous form are the following:

- Electric Conductivity
- pH
- Dissolved Oxygen
- Total Dissolved Solids
- Temperature

Some of the parameters listed above require a specific probe to be measured, while some of them can be measured by the same probe.

After a certain amount of time the probes must be calibrated or, in the case of pH, replaced. The average time before a calibration is required depends on the selected probe and the water quality being sampled.

The water quality of the reservoir depends on the time of the year. During summer the quality is lower due to the amount of algae present, but during autumn, winter and spring, the water quality significantly improved and should not deteriorate the probes.

As a recommendation, the probes should be calibrated every 4 months and sent to a technician every year, before summer to be properly examined.

3.1.1. Energy Requirements

Depending on the selected probe, the energy requirements can vary from 6 to 12 V DC. The energy requirements for each probe are shown in the Table 7:

Probe	Voltage	Type of Current
pH/ Temperature	4 AAA Batteries, 6V	DC
REDOX	4 AAA Batteries, 6V	DC
Electric Conductivity /Salinity/ Total Dissolved Solids	12 V	DC
Dissolve Oxygen	12 V	DC

Table 7 Probes Needed, with their respective voltages and type of current

As stated on section 2.2, all probes will be connected to a monitoring machine that will be in charge of collecting, storing and sending the measurements to a remote server. This means that the overall energy requirement is mainly for the monitoring machine.

The Datataker DT82EM series 4 was selected for this purpose. It can add up to 10 SCI-12 monitoring probes and send the information via Wi-Fi to an email account or FTP server. It also includes a GPS tracker necessary to keep track of the boat location. It has a peak power of 12W (for 1 A of current) and can work with voltages ranging from 10-30V DC.

*Figure 32 Datataker used to connect to the probes,
store the data and send it to a server. It also includes a GPS system. Source: Datataker.*

In order to achieve the necessary DC voltage, and taking into account that all the system is an AC system, a 12V DC rectifier will be used to transform the AC current to DC current.

For all the specifications on the data taker refer to the Annex 8.

3.2. Water Treatment by Electro-Coagulation

As stated on Section 2.3, the Electrocoagulation treatment for water is capable of treating different types of pollutants, however in order to achieve maximum efficiency, for a specific pollutant treated, the following design parameters must be taken into account:

- Electrode arrangement, material, shape and distance
- Pollutant concentration
- Current density
- Initial pH
- Electrolysis time

3.2.1. Electrode Arrangement, Material, Shape and Distance

There are three types of electrode arrangements:

- Monopolar parallel: the anodes are connected to each and the cathodes are connected to each other. Each pair is connected to the external energy supply.
- Monopolar series: only the two outermost electrodes are connected to the external energy supply while the pair of inner electrodes are connected to each other, without a connection to the outer electrodes.
- Bipolar series: the two outermost electrodes are connected to the external energy supply, but the inner electrodes are bipolar electrodes and are not connected to each other.
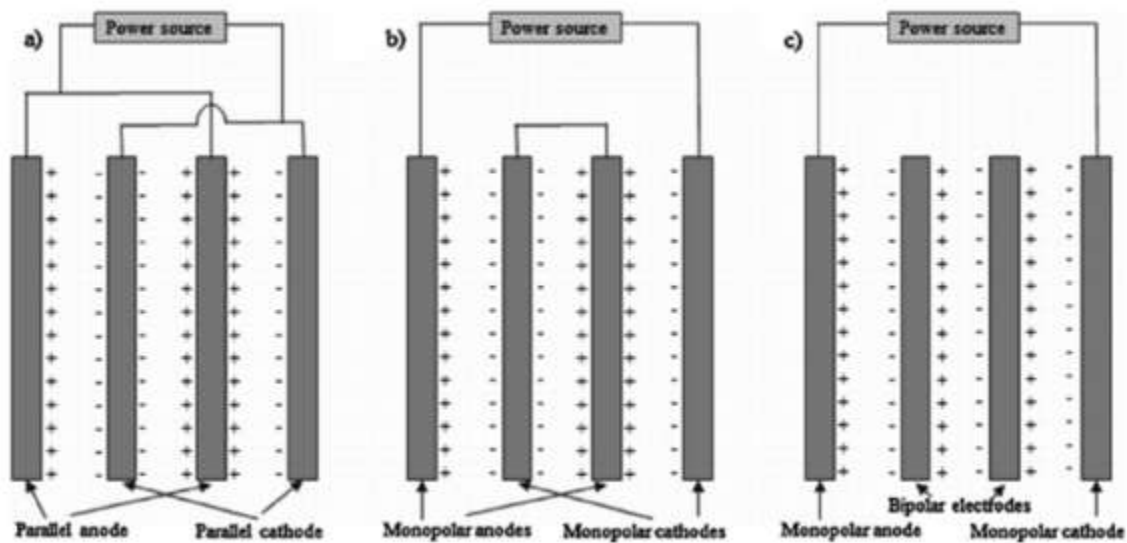
Figure 33 Different EC Arrangements.
a) monopolar parallel; b) monopolar series; c) bipolar series. Source: Can et.Al.

Several studies conducted for the different configurations showed similar results regarding effectiveness on color and turbidity removal. However, the monopolar configuration is the best way to treat wastewater and oily water.

Electrode material is one of the most important aspects of the design. Depending on the material used, different pollutants can be treated reaching different effectiveness levels.

Normally, in electrocoagulation both electrodes are of the same material, being the most commonly used Iron and Aluminum. They both have similar effectiveness in the removal of organic compounds, but iron is better to remove turbidity and the ion produced by iron is less contaminant to the water.

Regarding aluminum, a study conducted by *Can et. al.* showed that aluminum can be used to treat Arsenic on water to a high degree of effectiveness. Resulting on a removal between 90-99 %, depending on retention time, arsenic concentration and current density.

Figure 34 illustrates the results of the study.
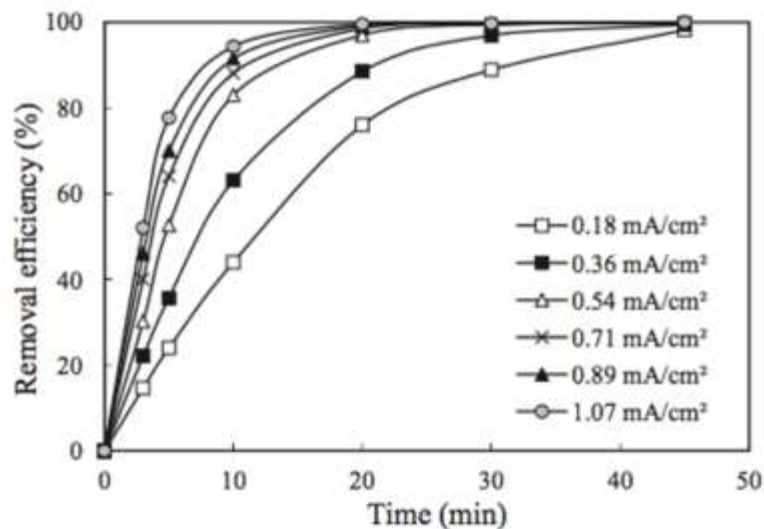
Figure 34 Removal Efficiency vs Retention Time
for different current densities for the removal of arsenic on water; arsenic concentration 50 mg/l. As seen, the higher the current density lower retention time is required to achieve a very high effectiveness, around 25 minutes for a efficiency of 99%. Source: Can et.Al.

Regarding the shape of the electrode, normally the most effective are plane electrodes, plus they are easy to clean, which avoids passivation of the electrode.

Finally, it is important to keep in mind that the inter electrode distance affects the performance of the electrolysis. The higher the distance, the higher the ohmic drop and lower the performance. The performance is reduced due to a lower mass transfer. Moreover, the distance impacts on the cell voltage.

The distance between electrodes should be from 10 mm up to 30 mm.

3.2.2. Pollutant Concentration

Higher initial concentration of pollutants decreases the performance of the system because the amount of metal hydroxides produced is insufficient to coagulate the amount of pollutant.

3.2.3. Current Density

The current density determines the coagulant dosage rate, bubble production rate, size and growth of the flocs, which in term influence the performance.

Increasing the current density will produce more metal hydroxide which will lead to a higher pollutant removal. However, it has a limit where the efficiency drops due to parasitic reactions which result on oxygen production.

A study conducted by *Maha Lakshmi et al.* showed that increasing the current density from 10 to 20 mA/cm^2 increased the organic compounds removal from 87% to 90%, but that for current densities around 40 mA/cm^2 the efficiency decreased to 81%.

3.2.4. Initial pH

The solution pH is a key operating factor because it directly influences the solution conductivity, dissolution of electrodes, separation of hydroxides and Zeta potential of the colloidal particles. It is important to keep in mind that during the electrolysis the pH will vary.

Since the electrodes are made of Al or Fe, both depend on the water pH to determine the oxidation of the ion on water. On highly basic solutions $Fe(OH)_4-$ and $Al(OH)_4-$ are formed, which are weak coagulants.

pH must be around 3-8 in order to have a higher efficiency, depending on the pollutant to be removed. For example, for the removal of organic matter and arsenic, a pH of 4 is commonly used.

For the removal of arsenic, pH plays a predominant role since depending on its value, different forms of arsenic (Arsenate (V) or Arsenite (III)) will be found in water. Both forms can be treated to a high degree of efficiency by Electrocoagulation.

3.2.5. Electrolysis Time

The pollutant removal efficiency increases as the retention time of the electrolysis increases. However, after the most efficient retention time is achieved, the efficiency will not increase further and will remain on the same value. This is because sufficient amount of flocs are available for the removal of the pollutant.

3.2.6. Energy Requirements

The electrolysis can be made using either AC or DC current. DC current is the most commonly used and easier to operate, but it causes the anode to dissolve and the passivation on the cathode.

AC current, on the other hand, prevents passivation on the cathode which result in higher efficiency but requires that both anode and cathode be of the same material.

Because the AC current for such low voltages is complicated to produce, a rectifier can be used to change the output voltage from the inverter to a 12V DC and then a special regulator is used to modify the DC voltage and current and adapt it to the needs of the system.

The amount of energy required is proportional to the current density that needs to be applied. For the removal of organic matter on water, current densities of 5 to 15 mA/cm^2 are used. The potential difference depends on the anode and cathode materials. In the case of Al-Al_3+ the potential is 1,66 V, and for Fe-Fe_3+ is 0,44 V.

3.2.7. Construction Requirements

The selected mode for the prototype is a continuous mode, making use of a solar pumping system in order to pump the necessary water into the prototype. Water will then be treated and stored on a container for later analysis.

In order to properly select the size of the container, first the retention time must be selected. According to the studies shown above, the proper retention time should be between 25-30

minutes. Since this is only a prototype and the size of the treatment plant does not have to be too big, a 5 L container is more than enough to store the necessary electrodes and a second 20 L container to store the treated water.

Taking in to account the 30-minute retention time and 5 L container, the pumping flow should be of 10 L/hr.

A Monopolar Parallel Arrangement was selected for the electrodes, with a spacing between electrodes of around 10-30 mm. This will allow us to test different lengths and analyze the effectiveness of the treatment for different spacing.

Figure 35 illustrate the design of the plates:
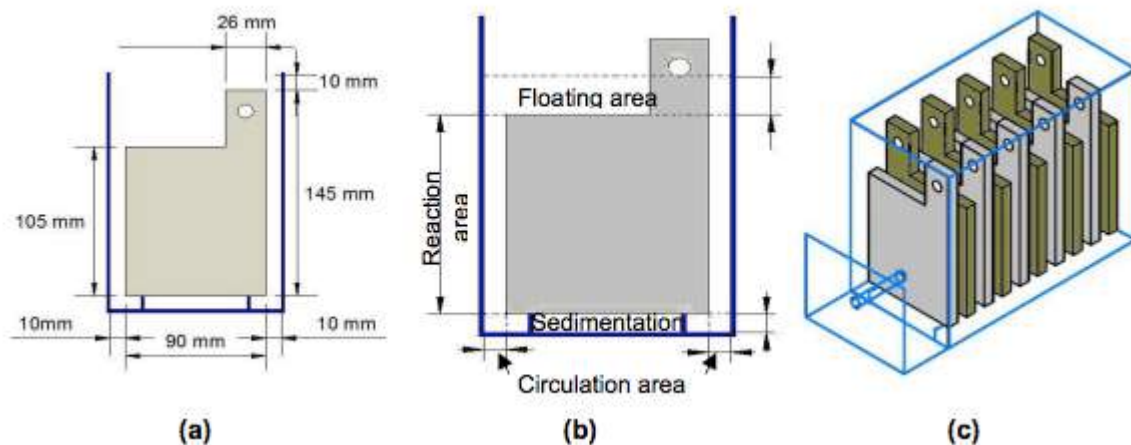
Figure 35 a) Electrode dimensions, b) cell areas: reaction, sedimentation, flotation, and circulation; and c) electrode distribution inside of the reactor and configuration

A total amount of 10 electrodes should be used, 5 anodes and 5 cathodes. The unused space will be used for the sedimentation of the flocs after the flocculation.

The overall design of a continuous flow electrocoagulation treatment prototype should be as shown on Figure 36.
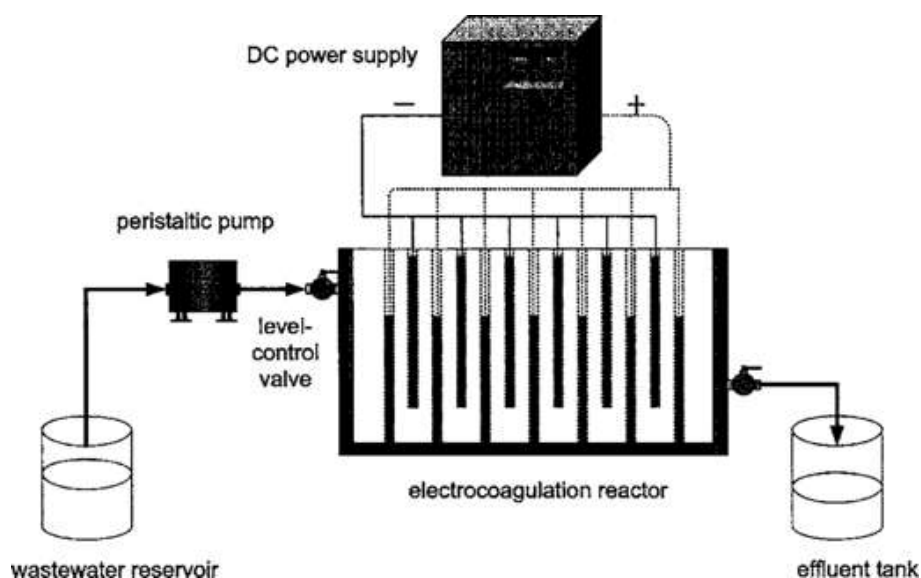
Figure 36 Design of a Continuous Electrocoagulation Water Treatment Plant.
Source: Den et.Al

In order to complete the design some other devices are needed, such as the pump and a storage tank for the accumulation of the treated water.

The pump is discussed on the section 3.5.

3.3. Algae Treatment by Ultrasound

The ultrasound equipment does not require a big amount of energy, making it ideal to work on solar photovoltaic energy.

Each ultrasound unit requires 24 V DC and 5 W of power which means that it can easily run by solar power. One device has a range of around 250 m so normally two devices are attached to the solar panels in order to cover more ground, such as is illustrated in the Figure 37.
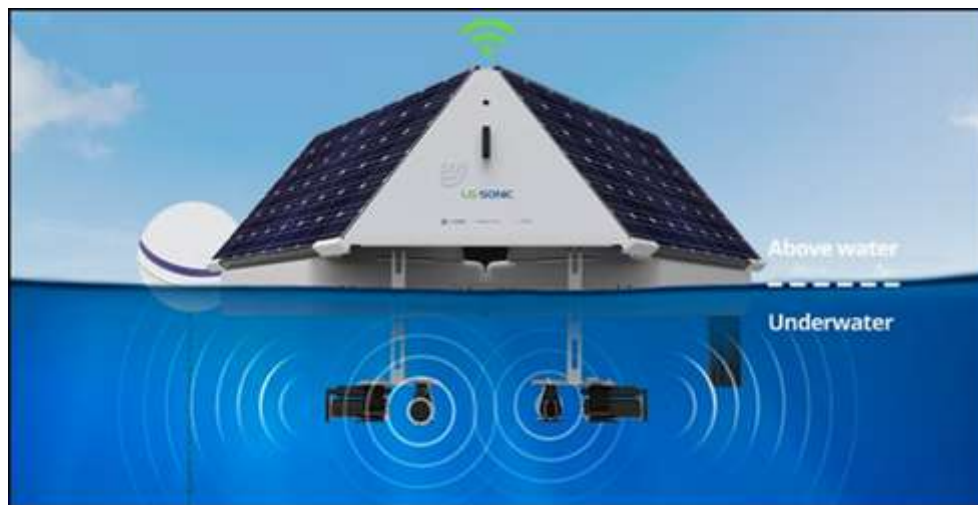
Figure 37 High Frequency Ultrasound powered by Solar Panels.
Source: LG Sonic

Once the ultrasound is working, the correct frequency able to disrupt the algae must be found. This may require some time since the treatment can take up to 4 weeks to work.

This means that finding the right frequency to effectively attack the algae can be a time consuming job and is why some devices come with predetermined frequencies based on former studies. Normally, the algae have its resonance frequency from 22 kHz to 28kHz.

The type of algae present in Salto Grande is Microcystis aeruginosa. There are several studies show that the ideal frequency necessary to treat these algae can range from 20 kHz to 150 kHz. The variation on frequency depends on the power of the device used.

Because the system is an AC system and this ultrasound device demands DC current, a 24V rectifier will be needed to transform the AC current to DC current.

The system also comes with a computer that stores the data measured by the device and later sends it to a remote server. It also comes with a couple monitoring probes that can be used to measure the Chlorophyll A and turbidity of the water. These two indicators are important to assess the effectiveness of the treatment.

The Specifications on the LG Sonic device can be seen on the Annex 7.

3.4. Solar Mobility of the Floating Solar Power Plant

As stated on section 2.5, the required engine necessary to move the boat is a Permanent Magnet Synchronous Motor (PMSM), so a PMSM of 1HP (1HP = 745.7 W) was power selected. This motor will either use solar energy directly or the battery bank installed on the boat.

The selected brand is a VOLCANO ELECTRIC PMSM, which requires a voltage of 208/230V, has a maximum power of 750 W and a rotating speed up to 3000 rpm.

This motor will be attached to a propeller that will move the boat at a slow but steady speed.

It is estimated that this motor will be working around 4 hours a day at an average power of 750 W.
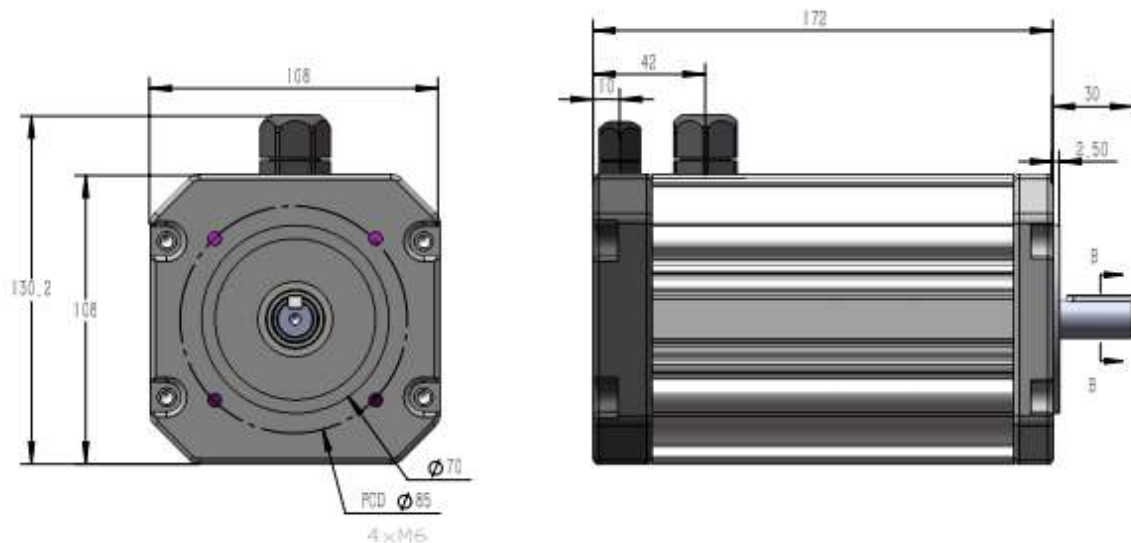
Figure 38 PMSM 1HP 220V motor.
Source: Volcano Electric

The motor needs to be completed with a controller to correctly drive the PMSM motor. The selected controller is a Volcano Electric Controller, model FS50L-0R7-2.

The test results of the PMSM and layout can be seen on the Annex 5.

3.5. Water Pumping

The water pump will be used mainly for pumping water into the electrocoagulation prototype treatment plant.

In order to properly select the solar pump, the water flow and the pumping height must be considered. In the specific case of the Floating Solar Power Plant, the height must be around 5-10 meters in order to avoid collecting water near the surface. The water flow was calculated on section 3.2. and is 10 l/hr or 0.24 m^3/day.

Taking into account the amount of solar radiation on the Salto Grande Reservoir (1.80-1.85 MWh/m^{2}year) and the media of the amount of sun every day (6.97 hr/day), the hourly flow of the pump can be calculated as follows:

$$Qh(flow) = \frac{0.24 \frac{m^3}{day}}{6.97 \frac{h}{day}} = 0.03 \frac{m^3}{h}$$

On average, the pump should be able to supply 0.03 m³/h of water using solar energy.

Since the water is also needed to cleanse the solar panels and for underwater quality sampling, another flow must be added to the flow calculated for the treatment plant (0.03 m³/h).

However, the sum of these two flows is too small for any commercial pump to deliver, so a flow of 0.2 m³/h will be used.

The pump selected is submersible pump GRUNDFOS SPK 1-5/3 T-W-A-AUUV, which requires 250 W of power and a tension of 220-255 D or 380-440 Y V.

The characteristic curve of the pump and the operation point are illustrated on the Figure 39.
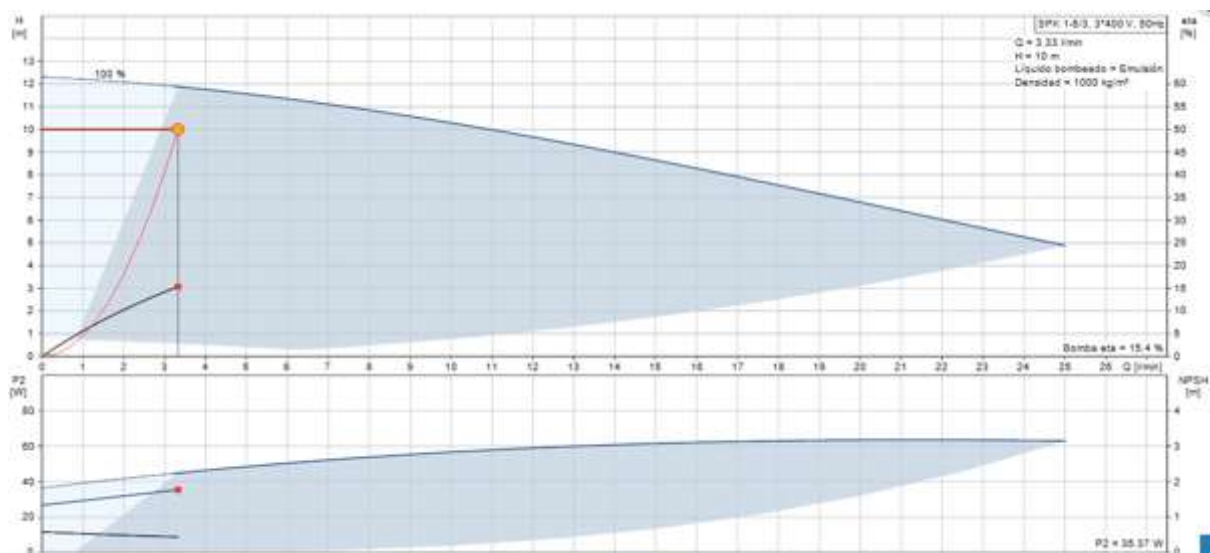
Figure 39 Characteristic curve and operation point for the selected pump.
Source: Grundfos

This pump efficiency at 10 meters deep is around 50% and 25% at 5 meters deep. Its NPSH is of 2m.

The pump will be working an estimate of 1 hour per day.

The data sheet can be found on the Annex 6.

3.6. Solar PV Design

In order to design the necessary solar PV panels and electronics, the maximum power output for each application previously described is needed. After the calculation is done, the losses and efficiencies of the equipment must also be taken into account.

The following are the main losses:

- Inverter losses, around 10%
- Rectifier losses, around 15%
- DC Cable losses, around 2%
- AC Cable losses, around 2%
- Shadings, around 1%
- Losses due to low irradiation, around 1%
- Losses due to dust or water, around 1%

Such as described on section 1.2, the method for the correct design starts with identifying the power of each application.

3.6.1. Power Calculation

To calculate the maximum power of the system, all power requirements are needed. In case the power is not known, the following equation can be used for its calculation:

$$P(W) = I(A) * V(V)$$

Where P is power in Watts, I is the current in amperes and V is the voltage in Volts.

Table 8 includes the energy requirements of each component.

Application	Voltage (V)	Current (A)	Power (W)
Monitoring Machine	12 DC	-	10
Electrocoagulation	1.66 DC	0.005-0.015	0.025
Ultrasound	24 DC	-	5
PMSM	220-240 AC	-	750
Pump	220-255 AC	-	250

Table 8 Energy Requirements for the different solar applications

It is important to state that for Electrocoagulation only the Aluminum probes were taken into account since they have a higher power demand than the Iron ones.

Also, since 2 devices are used for the ultrasound, the power requirements must be doubled to 10 W.

3.6.2. Daily Usage

The next step, as stated on section 1.2, is to estimate how much time on a regular day the devices will need to work.

With these values, an Energy Flowchart must be created stating when these devices will be working.

Table 9 states the estimated hours per day, power requirements and global energy consumption for each application.

Application	Power (W)	Hours per day	Energy (kWh)
Monitoring Machine	10	24	0.24
Algae Treatment	10	24	0.24
Water Treatment	0.025	1	0.000025
PMSM	750	4	3
Pump	250	1	0.25

Table 9 Estimated hours per day of usage and global energy requirements for a regular day.

This information is later used on a time span vs power chart for a regular day so as to really appreciate when the maximum energy requirements are necessary.

Table 10 shows which hours which applications are working at any given time of the day.

Hours	Power (W)	Application Working
1	20	Algae Treatment / Monitoring
2	20	Algae Treatment / Monitoring
3	20	Algae Treatment / Monitoring
4	20	Algae Treatment / Monitoring
5	20	Algae Treatment / Monitoring
6	20	Algae Treatment / Monitoring
7	20	Algae Treatment / Monitoring
8	20	Algae Treatment / Monitoring
9	20	Algae Treatment / Monitoring
10	770	Algae Treatment / Monitoring / PMSM
11	770	Algae Treatment / Monitoring / PMSM
12	20	Algae Treatment / Monitoring
13	270	Algae Treatment / Monitoring / Pump
14	20	Algae Treatment / Monitoring
15	770	Algae Treatment / Monitoring / PMSM
16	770	Algae Treatment / Monitoring / PMSM
17	20	Algae Treatment / Monitoring
18	20	Algae Treatment / Monitoring
19	20	Algae Treatment / Monitoring
20	20	Algae Treatment / Monitoring
21	20	Algae Treatment / Monitoring
22	20	Algae Treatment / Monitoring
23	20	Algae Treatment / Monitoring
24	20	Algae Treatment / Monitoring

Table 10 Power requirements for every hour of a regular day on the Solar PV Boat.

Based on this information, the following Energy Flowchart was drawn:
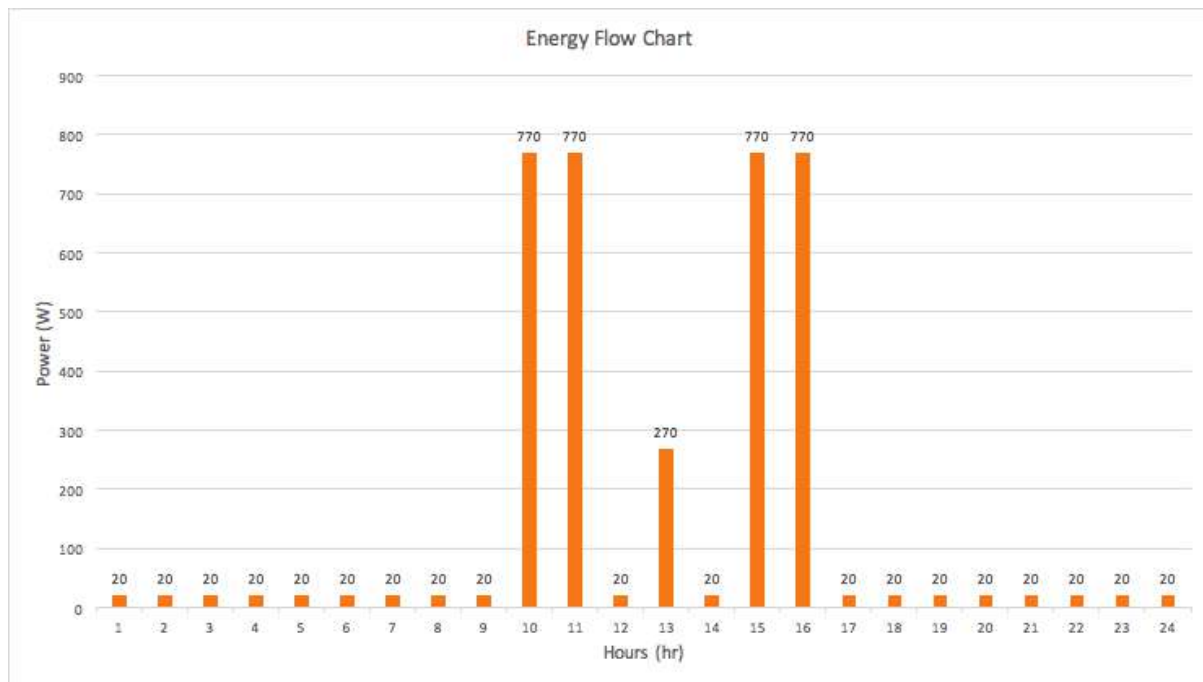
Figure 40 *Energy Flowchart for the Solar PV Boat.*

3.6.3. Solar Panels and Battery Storage Calculation

Due to the space restriction of the Solar PV Boat, one must select a specific amount of energy to design the solar panels and the battery storage.

Also, since some devices will need AC (Pump and PMSM) while others need DC (Algae treatment, Monitoring of the Water Quality and Water Treatment), a rectifier will be used to convert the AC current to DC current.

This type of configuration will prevent the need to design two power systems on the solar boat.

3.6.3.1. Solar PV Panels

Since the boat must be able to function during the whole year, the irradiation of the lowest month must be taken into account. For the selected location, these months are June and July with an average irradiation on a plane surface of 2.5 kWh/m^2.

This value was taken from the simulation of the "SOLARGIS" in the Salto Grande Reservoir.

Since the boat will be moving around the reservoir, the boat will have different angles regarding the sun (azimuth) and if an inclination is given to the panels, some of them might not receive any irradiation at all during some time of the day.

In order to avoid this situation, no inclination was given to the panels, placing them on a horizontal position. This will also eliminate the need of adding a correction factor due to inclination and azimuth.

The solar panels selected for the Solar PV Boat are the Jinko Solar JKM320PP - 72 panels.

The specifics of this panel model can be found on the Table 11.

Model	JKM320PP - 72
Cell Type	Monocrystalline / N-type
Cell Configuration	72 cells (6x12)
Module Dimensions (L x W x H)	1,956mm x 992mm x 40 mm
Weight	26.5 kg
Maximum Power (Pmax)	320 W
MPP Voltage (Vmpp)	37.4V
MPP Current (Impp)	8.56 A
Open Circuit Voltage (Voc)	46.4 V
Short Circuit Current (Isc)	9.05 A
Efficiency	16.49%

Table 11 Specifications for the JKM320PP - 72.
Source: Jinko Solar.

The premise taken in the design of the solar panel array is that the panels will provide enough energy on a day to charge the battery storage.

The battery storage will have the capacity to allow a 4-hour usage of the PMSM and a 24h usage of the Algae Treatment and Water Quality Monitoring. Taking the inverter, equipment efficiencies, AC/DC cables and rectifiers losses into account, a necessary energy of 4.3 kWh.

The whole calculation starts with the m^2 of solar panel required to provide the 4.3 kWh of energy. The following equation is used for this calculation:

$$A(m^2) = \frac{E(kWh)}{G\left(\frac{kWh}{m^2}\right) * \eta}$$

Where, E the energy required in kWh (4.3 kWh), G the irradiation of the lowest day of the year in kWh/m^2 (2.5 kWh/m^2), and η the solar panel efficiency (16.49%). For the selected scenario the total surface of panels needed is 10.4 m^2.

Taking the surface of a Jinko Solar panel of around 2m^2 into account, we can conclude that a total of 5 panels can provide almost all the necessary energy needed on a day.

During the daylight, these amount of panels will be able to provide energy to the applications easily while charging the batteries.

The specification for the solar panel can be seen on the Annex 2.

3.6.3.2. Inverter

The inverter will be used for the AC Pump and the PMSM motor in order to meet with the high voltages requirements (220-250 V).

In order to calculate an inverter, all the AC power demands of the applications must be considered and a 20% increase must be added for safety measures.

In this case, the output load of the inverter is around 1kW so the inverter should at least be capable of handling 1200W of power.

The selected inverter is an Growatt SPF 3000TL HVM 48P, which can handle an input power of 2400W (higher than the 1600W given by the 5 solar panels) and an output power of 3000W.

Another important aspect is the maximum current needed by the loads, which is calculated by:

$$I(A) = \frac{P(W)}{V(V)}$$

where, I is the Current in A, P is power in Watt and V is tension in volts.

The device that demands the highest current is the PMSM motor, as it requires a current of around 3.4A. These needs are within the ranges that the inverter can provide.

For the complete specifications refer to the Annex 3.

The system can be completed by the addition of a small device that allows all the information from the inverter to be sent, via Wi-Fi, to a remote server.

3.6.3.3. Solar Panel Array

The selected inverter can only work with a range of 60 - 115 V of input voltage. If all panels are connected in parallel, the maximum voltage of all the array is only the Nominal Voltage of one panel, and that is 37.4V. This value is not in the input voltage range of the inverter so this type of connection is not functional. In order to provide the necessary input voltage, panels need to be connected in series.

The connection will be in two sections, each section connected in parallel to the inverter. Since the inverter selected has only one MPPT tracker, this means that the sections of panels has to be homogeneous in order to achieve maximum power. To achieve the maximum power, the sections will be conformed by 3 panels connected in series and each in parallel to the inverter. This type of array will ensure that the MPPT is achieved for both sections at all moment.

The type of connection specified consist on 6 Jinko Solar Panel, and not 5 as calculated before. This will ensure that the batteries are fully charged on a day, and can also extend the daily usage of the solar PV boat, since more energy is available.

The sections will give a nominal voltage of 112.2V, which is in range of the input values of the inverter (60-115V).

The parallel connection of the two sections of solar panels will result on a nominal current of 17.12A, which is lower than the 40A maximum input current of the inverter.

3.6.3.4. DC Solar System

Some of the devices on the solar PV boat, such as the Monitoring of the Water Quality, Algae Treatment and Water Treatment, require a DC voltage input,

The inverter is connected to the panels and all the equipment, so in order supply the correct type of current, a SMPS is used to change the AC current of the inverter to DC current.

Analyzing the DC voltage needs of the equipment, there is a 24V voltage need for the Algae Treatment and 12V voltage for the Monitoring Water Quality. The Water Treatment also requires a 12V SMPS but it must be followed by a DC/DC variable converter to supply the necessary 1.66V.

The power of the SMPS depend on the equipment connected to it, so for the Algae Treatment and Monitoring Water Quality to work, 10W SMPS are needed. For the Water Treatment the power of the SMPS can be of 5W.

3.6.3.5. DC/DC Variable Converter

The Water Treatment by Electrocoagulation requires a very low voltage (1.66V) in order to dissociate the aluminum ions from its solid state into the water. A lower voltage will not dissociate the aluminum and a higher voltage will result on a low efficiency. Hence the need for a special DC/DC variable converter to produce this voltage.

The DC/DC converter type selected is a LTC3780 DC which can modify voltages in a range of 1 to 30 Volts. It can also modify the output current from a range between 300mA to 7 A. The lower level on current output is still to high for the Water Treatment by Electrocoagulation, but using the help of ITBA Alumni a correct design can be adapted to the output current needs.

3.6.4. Battery Storage and Maximum Scenario

As stated before, the battery storage must be big enough to provide the 4.3 kWh of energy required to supply the PMSM motor for at least 4 hours and the Water Quality Monitoring and Algae Treatment for 24 hours.

The battery selected is a LEOCH VRLA AGM 230Ah 12V battery and the following equation can be used to calculate the stored energy:

$$E(Wh) = 230\,Ah * 12V * \eta = 2484\,Wh$$

The battery efficiency is around 90%. For a correct usage of the batteries they must not be emptied further than 50% of its storage capacity (DoD 50%). Taking this factor into account, the actual amount of energy the battery can supply is 1.24 kWh.

The inverter selected is capable of also charging the batteries, but the inverter requires a battery storage of 48V. To achieve 48V, 4 batteries need to be connected in series.

One battery bank, conformed by 4 batteries in series connection, can store up to 9.9 kWh of total energy, but taking the 50%DoD, it can actually supply 4.97kWh of energy.

Because the amount of energy needed is 4.3kWh, one battery bank of 4 batteries in series is enough to supply the necessary energy.

3.6.4.1. Maximum Scenario

The last step defined by the design method in section 1.2, is to estimate the maximum scenario for the solar PV boat. The amount of energy needed is then compared to the amount needed on a regular day and the highest value will be selected as the battery storage system.

As stated before, the maximum scenario applies only to vital applications, which are Algae Treatment and Monitoring of the Water Quality. The specified time span is 5 days without sun.

For this scenario the amount of energy required is 2.9 kWh for the entire 5-day span, taking into account equipment efficiencies and the losses due to the rectifier, inverter and cable.

The value of energy demand is lower than the value used to design the battery storage for a regular day, so the battery bank calculated before can also be used to provide the energy for the maximum scenario.

The battery storage system consists of 4 LEOCH VRLA AGM 230Ah 12V batteries connected in series, capable of providing 4.97kWh at 50% DoD. All this energy can actually make the vital applications work for up to 8 days.

For the specifications on the LEOCH battery refer to the Annex 4.

3.6.5. System Layout

Figure 41 shows the layout for the Solar PV System:
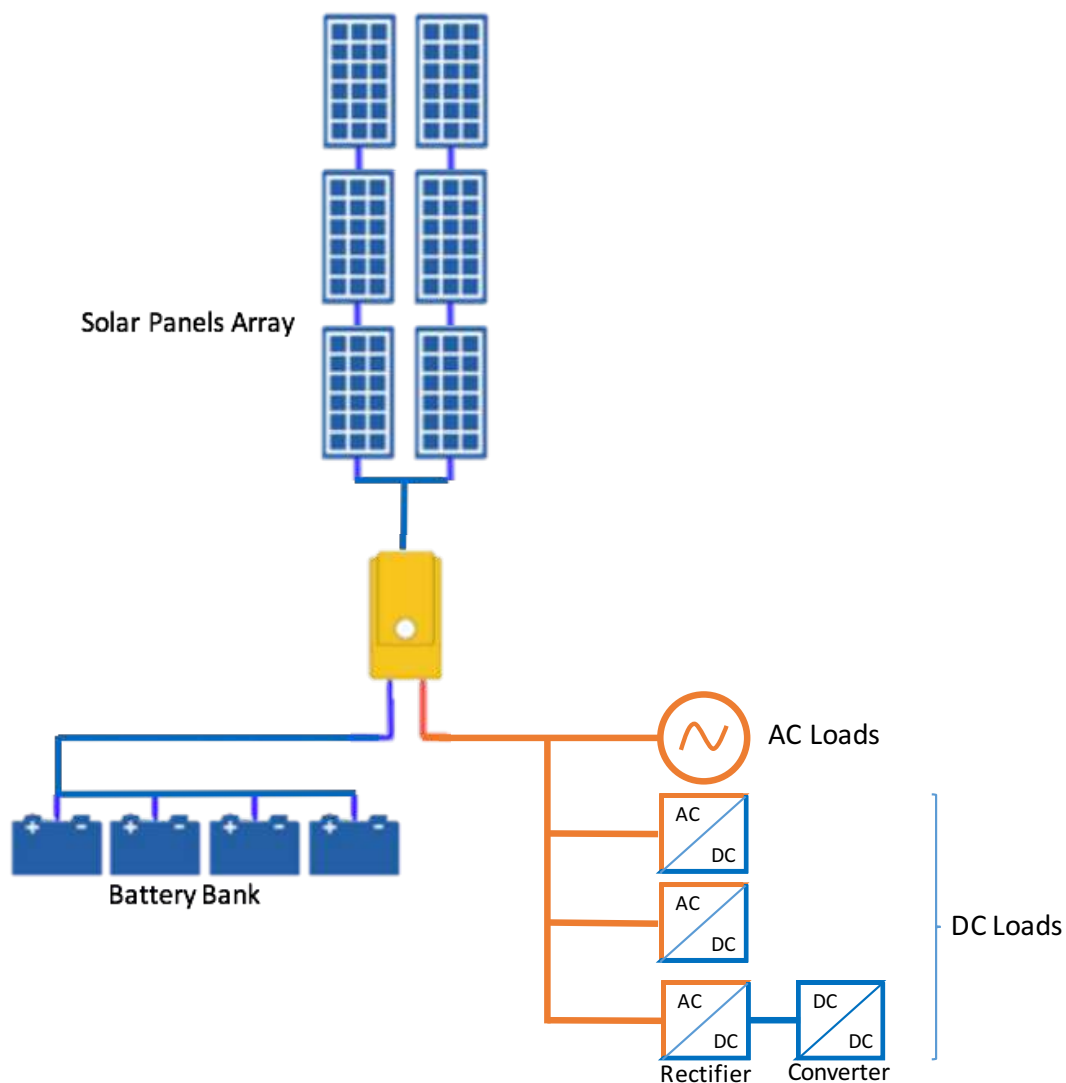
Figure 41 *Approximate Layout of the hole Solar PV System*

3.6.6. Cable Selection

The final step is the selection of the cables for each of the different sections of the whole system.

The following is the equation used to estimate the cross section of the necessary cable:

$$S(mm^2) = \frac{2 * L(m) * I(A)}{k(\frac{m\Omega}{mm^2}) * V(V)}$$

Where, L is the length on the cable in meters, I is the current on that cable in Amperes, k is the electric conductivity of the material in m/Ωmm^2, and V is the voltage drop on the cable, in Volts.

The voltage drop is calculated as a percentage of the nominal voltage and it depends on which elements are connected [Aparicio, 2009]:

- Between solar panel and inverter 3%
- Between inverter and battery 1%
- Between rectifier and inverter 1%
- Between rectifier/inverter and the loads 3%

All cables will be copper based so the electrical conductivity is 56 m/Ωmm^2.

The length of cable used is an approximation of what will be required to connect each equipment. And the current used is the one circulating between the equipment for each section.

- Cable between solar panels and inverter:

$$S(mm^2) = \frac{2 * 8m * 17.12A}{56\frac{m\Omega}{mm^2} * (0.03 * 37V)} = 4.4 \; mm^2$$

- Cable between inverter and battery:

$$S(mm^2) = \frac{2 * 3.5m * 10A}{56\frac{m\Omega}{mm^2} * (0.01 * 48V)} = 2.6 \; mm^2$$

- Cable between rectifier and charges:

$$S(mm^2) = \frac{2 * 10m * 0.8A}{56\frac{m\Omega}{mm^2} * (0.03 * 24V)} = 0.4 \; mm^2$$

- Cable between inverter and charges:

$$S(mm^2) = \frac{2 * 8m * 3.26A}{56\frac{m\Omega}{mm^2} * (0.03 * 220V)} = 0.14 \; mm^2$$

Table 12 shows the length and cross section for each section of the system:

Section	Solar Panel - Inverter	Inverter - Battery	Rectifier - Charges	Inverter - Charges
Length (m)	8	3.5	10	8

Section	Solar Panel - Inverter	Inverter - Battery	Rectifier - Charges	Inverter - Charges
Cross Section (mm^2)	6	4	4	4

Table 12 Lengths and cross section of the cables used in each section of the system.

The 4 mm^2 of cross section cable will be Conducom SA model SFTF0104 N, and for the 6mm^2 cross section Marlew model PS 0160 NE.

Conclusion

The idea of the whole design was to achieve electrical values that consist on AC current of 220V and frequency of 50Hz, thus allowing the usage of commercial equipment.

AC Solar System

Due to space restrictions on the Solar PV Boat, the solar panels need be able to provide the necessary energy to power the PMSM motor for 4 hours, and Water Quality Monitoring and Algae Treatment for 24 hours.

With that energy value, it was calculated that 6 Jinko SP-JKM 320PP - 72 solar panels can provide enough energy to supply them and almost fully recharge the batteries. The panels will be divided in two sections, containing 2 and 3 solar panels each, connected in series, while both sections are connected in parallel to the inverter.

Regarding the battery storage, 4 LEOCH VRLA AGM 230Ah 12V are needed. All of them connected in series.

The inverter selected is a Growatt SPF 3000LT HVM 48V.

DC Solar System

For the DC devices, SMPS will be used to transform the AC current to DC current. The Algae Treatment demands a 220VAV/24VDC SMPS and the Water Quality Monitoring demands a 220VAC/12VDC SMPS.

For the Specific case of the Water Treatment, a SMPS of the 220VAC/12VDC can be used, but it needs a DC/DC variable converter to adjust the necessary voltage. The converter type can be a LM317, in order to supply the necessary 1.66V.

It must be remarked that another study must be conducted on the low tension levels (12V and 24V) and DC current, with the objective on minimizing the interfaces and maximizing the efficiency. This study will allow to work on lower tension in a safer way.

All the equipment specifications can be seen on the Annexes.

3.7. Solar PV Boat Design

All the applications and the solar PV system, including batteries, should be able to fit on a boat. The boat selected should also have some special arrangements made, in order to fit everything and allow a free movement around the boat.

The type of boat recommended for the project is a Small Lobster Boat, such as the shown on Figure 42.
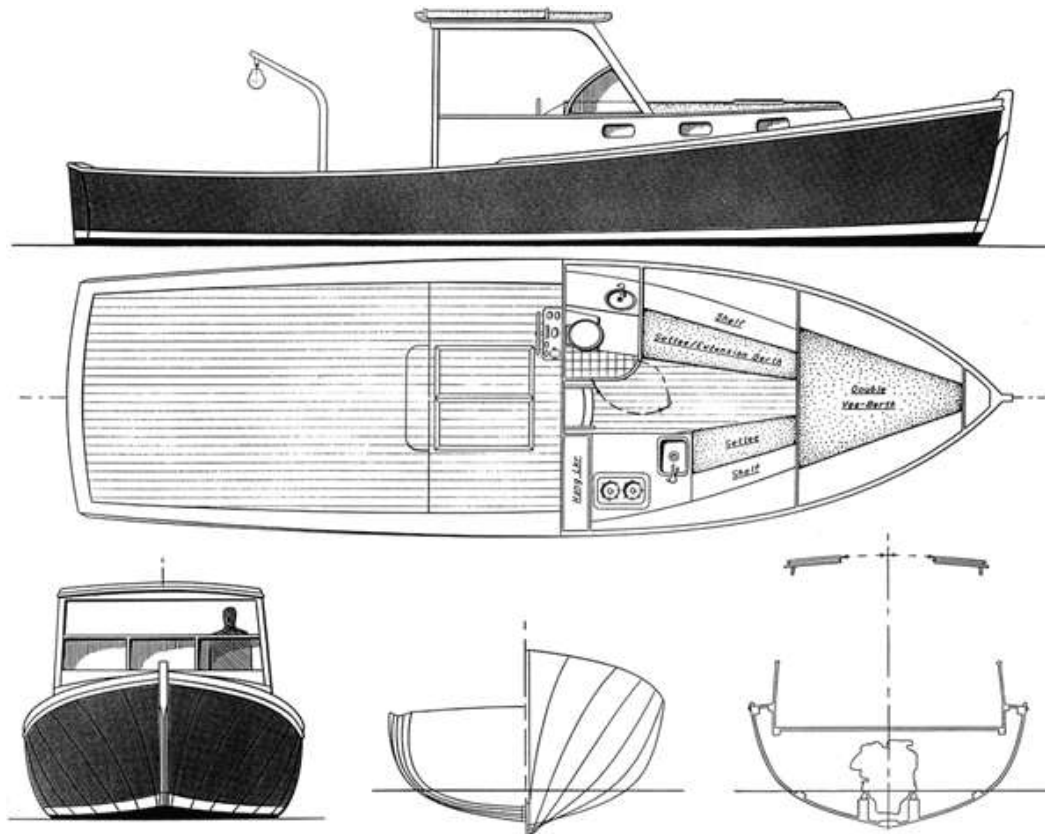
Figure 42 Normal Design of a Small Lobster Boat.
Source: http://boat118.blog.fc2.com/blog-entry-36.html

This type of boat is design to have lot of space on the back, that can be used for the necessary equipment. The only modification, regarding the blueprint seen above, is that the roof should be taken down, and a rail system needs to be installed for the solar panels. Eliminating the roof will also give a better cooling system for the panels causing them to have a higher efficiency.

The railing system needs to be at least a 12m^2, in order to be able to have all 6 Jinko SP-JKM 320PP - 72 solar panels on its roof.

For the battery storage, the bow offers a small cabin, where all the batteries can be stored and shaded from the sun and water. Also the regulator, inverter and other appliances can be stored here.

The most important aspect to take into account is that the overall boat, including solar system and applications, can not exceed the 2 tons' displacement weight, in order to achieve the 4 knots speed with a 1HP engine. The Solar system weights an overall of 400 kg (4 batteries of 65kg each, 6 panels of 26kg each, inverter 5kg and 3 rectifiers 0.42kg), while the PMSM,

pump, probes, Ultrasound and water treatment, adds another 50kg, leaving more than a ton for the whole boat and people.

The last modification that need to be made is the propeller. The propeller will be attached to the PMSM motor, and will introduce a skeg for better maneuvering,

The PMSM motor need to be coupled with a single shaft using a chain drive system. The roller chain/sprocket combination can be used to allow gearing changes based on propeller rpm during trail runs. The design gear ratio is recommended to be a 1.3:1 (shaft/motor).

The design can be seen on the Figure 43.

Figure 43 Propeller attached to a couple of PMDC motors.
Source: Successful Design and Construction of a Solar Electric Boat Nusrat and Muavenet, Ozden, Cansin, Istanbul Technical University (2009).

Because this type of propeller has a maneuvering complication for sharp corners, another modification needs to be made to the boat, and that is the introduction of maneuvering flaps. These flaps needs to be installed as the image shown on Figure 44.
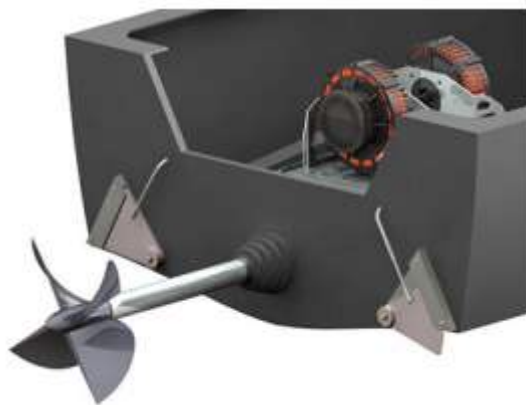
Figure 44 Maneuvering flaps installed on boat.
Source: Successful Design and Construction of a Solar Electric Boat Nusrat and Muavenet, Ozden, Cansin, Istanbul Technical University (2009)

These interceptors/flaps were positioned on transom stern of the boat and controlled by drive system directly with morse cables and connected to articulated drive train. The final product needs to be as the illustration on Figure 45.

Figure 45 Final Maneuvering system design for the boat.
Source: Successful Design and Construction of a Solar Electric Boat Nusrat and Muavenet, Ozden, Cansin, Istanbul Technical University (2009)

The flaps can be constructed from AISI 316 steel to avoid corrosion and obtain high strength. Holding supports can be covered inside with Teflon to decrease friction. This system has nearly no effect on the overall weight of the boat and give an extraordinary maneuverability.

For more mechanical and electrical connections one can refer to the paper "Successful Design and Construction of a Solar Electric Boat Nusrat and Muavenet, Ozden, Cansin, Istanbul Technical University (2009)", on section 6 "Mechanical Systems - Endurance Configuration" and Section 7 "Electrical Systems". One these two sections all the information regarding mechanical advantages and all the electrical is detailed. Also some advices are given for the protection of the system.

4. Floating Solar Power Plant Budget

On this section the budget for the overall solar power plant will be analyzed. The budget is divided in two sections, one regarding only the Solar PV Design (Solar panels, inverter, batteries, etc.) and the other regarding the applications that will be installed on the solar boat.

The cost regarding the solar boat, or its improvements, will not be discussed in this budget. Leaving it cost to the Salto Grande Organization.

Some of the devices used, such as Rectifiers or the LTC3780 DC, can be designed by ITBA alumni during their regular courses. This will help to bring the overall budget down, but it will also give a learning opportunity for other students, resulting on a device that will fit perfectly the power demands of these applications.

In the

Table 13-14, the IVA tax is stated due that the provider is from Argentina. For the case of the applications of the Solar Boat, almost all of the applications need to be bought on other countries. The reason is that some of the equipment is not manufactured in Argentina, like the

PMSM motor and controller, or the LG Sonic Ultrasound. The only application that has the IVA tax is the Pump, that can be supplied by local distributors.

Solar System						
	Provider	Model	Quantity	Unitary Price (U$S)	IVA	Total Price (U$S)
Solar Panel	Jinko	SP-JKM 320PP 72	6	126.75	10.5	840.35
Inverter	Growatt	SPF 3000TL HVM	1	336.52	21	407.19
Battery	LEOCH	LPS 12-230	4	425.99	21	2061.79
Cable - 4mm^2	Conducom	SFTF0104 N	1	0.9	21	1.09
Cable - 6mm^2	Marlew	PS 0160 NE	1	1.61	21	1.95
Electric Materials	-	-	1	100	21	121
					Sub Total	3433.37

Table 13 Budget of the Solar PV System

Applications Machinery					
	Provider	Model	Quantity	Unitary Price (U$S)	Total Price (U$S)
PMSM	Volcano Electric	VOL-IEC80S750-2P	1	220	220
PMSM Controller	Volcano Electric	FS50L-0R7-2	1	132	132
Pump	Grundfos	SPK 1-5/3	1	2400	2975
Ultrasound	LG Sonic	XXL PLUS	2	2900	5800
Ultrasound monitor	LG Sonic	E line tester	1	772	772
Monitoring Probes	HANNA	HI 763133	1	410	410
	American Marine INC	PINPOINT Oxygen	1	140	148
	American Marine INC	PINPOINT pH	1	49	57
	American Marine INC	PINPOINT REDOX	1	75	83
Signal Sender	Growatt	WIFI - F	1	70	70
Datataker	Datataker	Series 4	1	1485	1485
				Sub Total	12152

Table 14 Budget for the Applications of the Solar Boat

The overall budget for the hole system and the applications adds up to **U$S 15,585.37**.

5. Conclusion

The proposed floating solar PV power plant will provide a platform that will facilitate the study of Salto Grande Reservoir's water ecosystem and could potentially be used as a pilot for technical training in the renewable energy field.

The plant, adapted to a boat, includes solar panels, inverter, rectifier, converter and data acquisition instruments. A battery pack is included to feed the equipment, to run a water pump for the plant maintenance and to power the boat with autonomy of 30 km.

For the design of the whole installation, a simple method is suggested to assess an optimum energy layout, avoiding any over dimensioning of the plant. Simulations of the system show secure energy supply for the proper performance of each component and ensured operation along the four seasons of the year.

The proposed array allows continuous monitoring of water parameters of interest, as pH, temperature, dissolved Oxygen, REDOX, electrical conductivity and amount of dissolved solids. The proposed array also allows an algae treatment by ultrasound. This last system includes a monitoring of the turbidity and Chlorophyll A, to assess the efficiency of treatment and, by the monitoring of these parameters, a proactive algae treatment can be put in place. Finally, the water treatment plant could be used as pilot platform for technical knowledge and capacitation.

Further work is required for the design of interfaces of low-tension equipment, in order to maximize the plant efficiency. Future students have the opportunity of getting involved through the manufacturing of electro components, such as rectifiers or converters, up to the modifications on the solar boat.

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7. Annexes

List of Annexes:

1. SolarGis Simulation
2. Solar Panel Datasheet
3. Inverter Datasheet
4. Battery Datasheet
5. PMSM Test Results and Layout
6. Pump Datasheet
7. Ultrasound Datasheet
8. Monitoring Machine Datasheet

ANNEX 1

SOLARGIS Simulation

YIELD ASSESSMENT OF THE PHOTOVOLTAIC POWER PLANT

Report number: PV-58389-1908-966
Issued: 23 August 2019 21:11 (UTC)

1. Site info

Site name:	Entre Ríos, Argentina
Coordinates:	**31° 16' 11.54" S, 57° 55' 53.53" W**
Elevation a.s.l.:	32 m
Slope inclination:	0°
Slope azimuth:	0° north

Annual global in-plane irradiation: **1808 kWh/m²**
Annual air temperature at 2 m: **19.1 °C**

2. PV system info

Installed power:	**1.6 kWp**
Type of modules:	crystalline silicon **(c-Si)**
Mounting system:	**fixed mounting, free standing**
Azimuth/inclination:	**0° (north) / 0°**
Inverter Euro eff.:	97.0%
DC / AC losses:	7.0% / 3.0%
Availability:	99.0%

Annual average electricity production: **2161 kWh**
Average performance ratio: **74.7%**

Location on the map: http://solargis.info/imaps/#tl=Google:satellite&loc=-31.2698734367,-57.9315347686&z=14

3. Geographic position
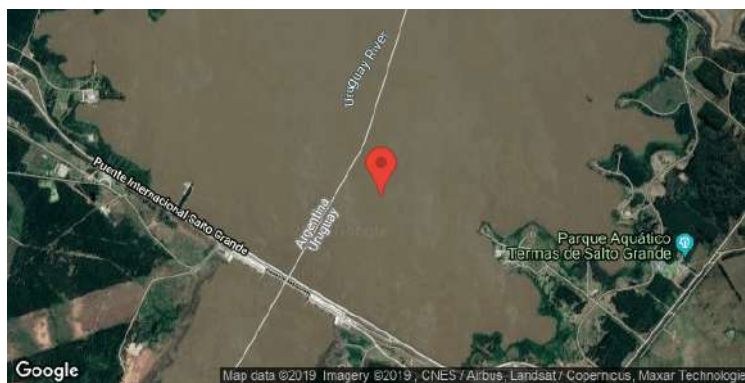
Google Maps © 2019 Google

4. Terrain horizon and day length
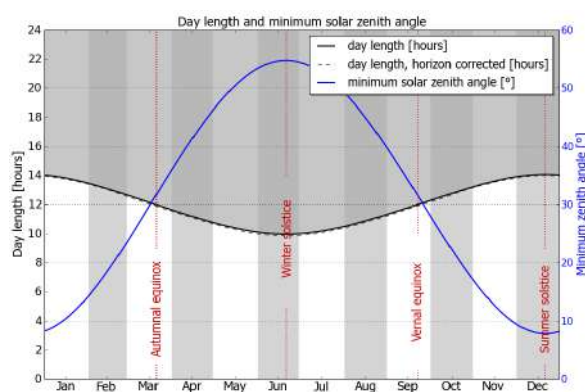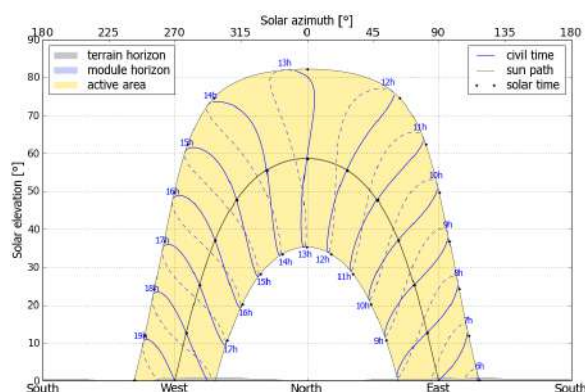
Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Blue labels show Local Clock Time.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

Site: Entre Ríos, Argentina, lat/lon: -31.2699°/-57.9315°
PV system: 1.6 kWp, crystalline silicon, fixed free, azim. 0° (north), inclination 0°

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh$_m$	Gh$_d$	Dh$_d$	T$_{24}$
Jan	228	7.34	2.09	27.2
Feb	177	6.30	2.01	25.7
Mar	166	5.35	1.70	23.5
Apr	121	4.04	1.29	18.7
May	95	3.06	1.16	14.8
Jun	75	2.50	0.98	12.5
Jul	90	2.90	1.06	11.7
Aug	113	3.65	1.37	14.2
Sep	139	4.65	1.66	15.6
Oct	174	5.61	1.90	19.0
Nov	207	6.90	1.95	21.6
Dec	224	7.21	2.11	25.0
Year	1808	4.95	1.60	19.1

Long-term monthly averages:

Gh$_m$ Monthly sum of global irradiation [kWh/m^2]
Gh$_d$ Daily sum of global irradiation [kWh/m^2]
Dh$_d$ Daily sum of diffuse irradiation [kWh/m^2]
T$_{24}$ Daily (diurnal) air temperature [°C]

6. Global in-plane irradiation

Fixed surface, azimuth 0° (north), inclination. 0°

Month	Gi$_m$	Gi$_d$	Di$_d$	Ri$_d$	Sh$_{loss}$
Jan	228	7.34	2.09	0.00	0.0
Feb	177	6.30	2.01	0.00	0.0
Mar	166	5.35	1.70	0.00	0.0
Apr	121	4.04	1.29	0.00	0.0
May	95	3.07	1.16	0.00	0.0
Jun	75	2.50	0.98	0.00	0.0
Jul	90	2.90	1.06	0.00	0.0
Aug	113	3.66	1.37	0.00	0.0
Sep	139	4.65	1.66	0.00	0.0
Oct	174	5.61	1.90	0.00	0.0
Nov	207	6.90	1.95	0.00	0.0
Dec	224	7.21	2.11	0.00	0.0
Year	1808	4.95	1.60	0.00	0.0
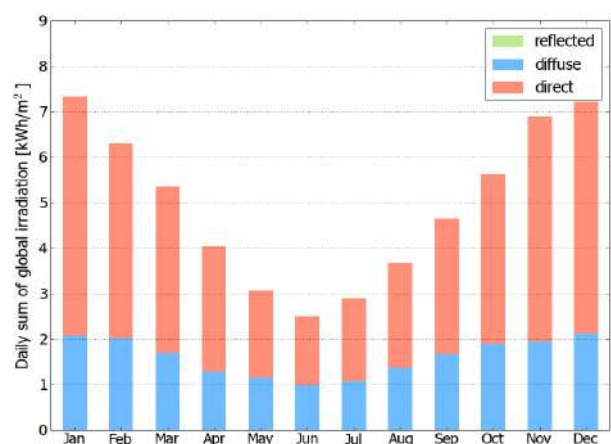
Long-term monthly averages:

Gi$_m$ Monthly sum of global irradiation [kWh/m^2]   Sh$_{loss}$ Losses of global irradiation by terrain shading [%]
Gi$_d$ Daily sum of global irradiation [kWh/m^2]
Di$_d$ Daily sum of diffuse irradiation [kWh/m^2]
Ri$_d$ Daily sum of reflected irradiation [kWh/m^2]

Average yearly sum of global irradiation for different types of surface:

	kWh/m^2	relative to optimally inclined
Horizontal	1808	90.6%
Optimally inclined (28°)	1996	100.0%
2-axis tracking	2699	135.2%
Your option	**1808**	**90.6%**

Site: Entre Ríos, Argentina, lat/lon: -31.2699°/-57.9315°
PV system: 1.6 kWp, crystalline silicon, fixed free, azim. 0° (north), inclination 0°

7. PV electricity production in the start-up
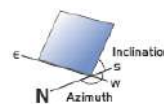
Month	Es$_m$	Es$_d$	Et$_m$	E$_{share}$	PR
Jan	164	5.29	262	12.1	72.0
Feb	129	4.59	206	9.5	72.9
Mar	123	3.96	197	9.1	74.1
Apr	92	3.07	147	6.8	76.0
May	73	2.35	117	5.4	76.8
Jun	58	1.92	92	4.3	76.9
Jul	70	2.25	112	5.2	77.7
Aug	88	2.83	141	6.5	77.5
Sep	107	3.58	172	8.0	77.0
Oct	131	4.24	210	9.7	75.5
Nov	154	5.12	246	11.4	74.2
Dec	163	5.25	260	12.0	72.8
Year	**1351**	**3.70**	**2161**	**100.0**	**74.7**

Long-term monthly averages:

Es$_m$ Monthly sum of specific electricity prod. [kWh/kWp]
Es$_d$ Daily sum of specific electricity prod. [kWh/kWp]
Et$_m$ Monthly sum of total electricity prod. [kWh]

E$_{share}$ Percentual share of monthly electricity prod. [%]
PR   Performance ratio [%]

8. System losses and performance ratio

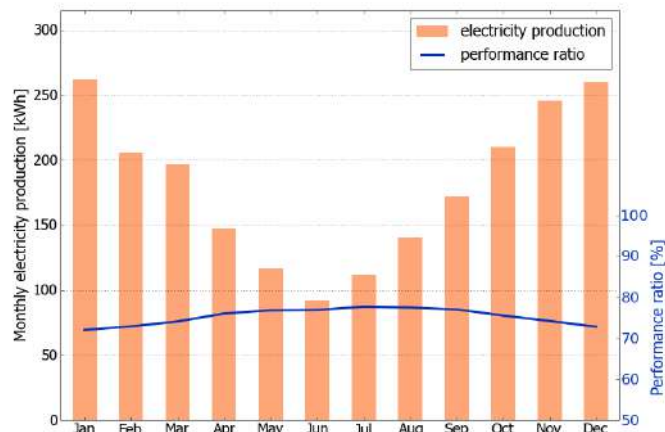| Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1808	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1808	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	1745	-63	-3.5	96.5	96.5
4. Conversion to DC in the modules	1559	-186	-10.7	89.3	86.2
5. Other DC losses	1450	-109	-7.0	93.0	80.2
6. Inverters (DC/AC conversion)	1407	-44	-3.0	97.0	77.8
7. Transformer and AC cabling losses	1364	-42	-3.0	97.0	75.5
8. Reduced availability	1351	-14	-1.0	99.0	74.7
Total system performance	**1351**	**-458**	**-25.3**	**-**	**74.7**

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at http://solargis.com/products/pvplanner/.

9. Solargis v21a - description of the database

Solargis is high-resolution climate database operated by Solargis s.r.o. Primary data layers include solar radiation, air temperature and terrain (elevation, horizon).

Air temperature at 2 m: developed from the CFSR data (© NOAA NCEP, USA); years: 1994 - 2011; recalculated to 15-minute values. The data are spatially enhanced to 1 km resolution to reflect variability induced by high resolution terrain.

Solar radiation: calculated from the satellite and atmospheric data:
- Meteosat PRIME satellite (© EUMETSAT, Germany) 1994 - 2015, 15-minute or 30-minute values for Europe, Africa and Middle East,
- Meteosat IODC satellite (© EUMETSAT, Germany) 1999 - 2015, 30-minute values for Asia,
- GOES EAST satellite (© NOAA, USA) 1999 - 2015, 30-minute values for Americas,
- GOES WEST satellite (© NOAA, USA) 1999 - 2015, 30-minute values for North America and Pacific,
- MTSAT satellite (© JMA, Japan) 2007 - 2015, 30-minute values for Pacific,
- MACC-II/CAMS (© ECMWF, UK) 2003 - 2015, atmospheric data,
- GFS, CFSR (© NOAA, USA), 1994 - 2015, atmospheric data,
- MERRA-2 (© NASA, USA), 1994 - 2002, atmospheric data.

This estimation assumes year having 365 days. Occasional deviations in calculations may occur as a result of mathematical rounding and cannot be considered as a defect of algorithms. More information about the applied data, algorithms and uncertainty can be found at: http://solargis.com/products/pvplanner/.

10. Service provider

Solargis s.r.o. , Milana Marečka 3, 84108 Bratislava, Slovakia; Registration ID: 45 354 766, VAT Number: SK2022962766; Registration: Business register, District Court Bratislava I, Section Sro, File 62765/B

11. Mode of use

This report shows solar power estimation in the start-up phase of a PV system. The estimates are accurate enough for small and medium-size PV systems. For suntracking simulations, only theoretical options are shown without considering backtracking and shading. For large projects planning and financing, more information is needed:
1. Statistical distribution and uncertainty of solar radiation
2. Detailed specification of a PV system
3. Interannual variability and P90 uncertainty of PV production
4. Lifetime energy production considering performance degradation of PV components.

More information about full PV yield assessment can be found at: http://solargis.com/products/pv-yield-assessment-study/.

12. Disclaimer and legal information

Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainty of measurements and calculations, Solargis s.r.o. cannot take full guarantee of the accuracy of estimates. The maximum possible has been done for the assessment of climate conditions based on the best available data, software and knowledge. Solargis s.r.o. shall not be liable for any direct, incidental, consequential, indirect or punitive damages arising or alleged to have arisen out of use of the provided report.

13. Contact information

This report has been generated for Tecno Inteligente SA, Lavalle 190, 6L, 1047, Ciudad de Buenos Aires, Argentina, http://www.solarlatam.com.

This document is electronically signed by Solargis s.r.o..

ANNEX 2

Solar Panel Datasheet

Jinko Solar

Building **Your Trust** in Solar

JKM320PP-72
305-320 Vatios
MÓDULO POLICRISTALINO

Tolerancia positiva 0/+3%

Fábrica con certificación ISO9001:2008,
ISO14001:2004,OHSAS18001
Productos con certificación IEC61215, IEC61730

Principales características

Célula solar 4 bus bar:
La célula solar 4 bus bar adopta una nueva tecnología para mejorar la eficiencia de los módulos, ofrece un mejor aspecto estético, lo que es perfecto para su instalación en los tejados.

Potencia Elevada:
Los módulos de 72 células policristalinos alcanzan potencias de hasta 320Wp.

Garantía Anti-Degradación Potencial Inducida (PID):
Se garantiza una degradación limitada de la potencia del módulo Eagle causada por la Degradación Potencial Inducida (PID por sus siglas en inglés) bajo condiciones de 60ºC/85% de humedad relativa para la producción en masa..

Rendimiento con baja irradiación lumínica:
El avanzado cristal y el texturizado de la superficie de la célula fotovoltaica permiten un resultado excelente en condiciones de baja irradiación lumínica.

Resistencia en condiciones climatológicas adversas:
Certificado para soportar rachas de viento (2.400 Pascal) y cargas de nieve (5.400 Pascal).

Resistencia en condiciones ambientales extremas:
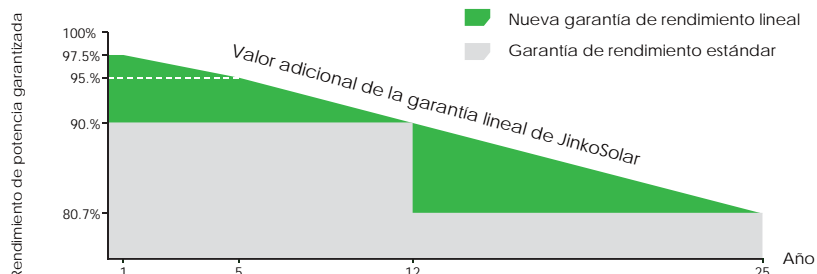Alta resistencia a la brisa marina y al amoniaco, certificado por TÜV NORD.
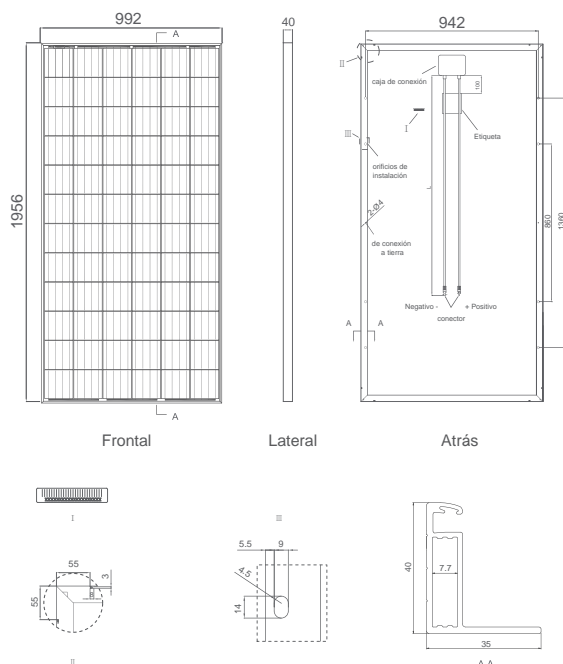
Coeficiente de Temperatura:
El coeficiente de temperatura mejorado reduce la pérdida de potencia en altas temperaturas.

GARANTÍA DE RENDIMIENTO LINEAL

10 Años de garantía de producto • 25 Años de garantía de potencia lineal

PV CYCLE   TÜVRheinland CERTIFIED   CE   MCS

Dibujos técnicos

992 | 40 | 942

caja de conexión
Etiqueta
orificios de instalación
de conexión a tierra
Negativo − + Positivo conector

1956

Frontal | Lateral | Atrás

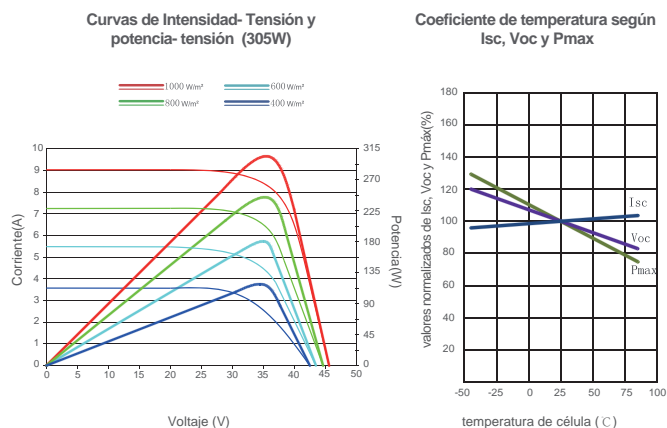55 | 55 | 3 | 5.5 | 9 | 14 | 4.5 | 7.7 | 40 | 35 | A-A

Embalaje

(Dos cajas = un palet)

25 pzs./caja, 50 pzs./caja, 600 pzs./40 'HQ contenedores

Rendimiento eléctrico y dependencia de la temperatura

Curvas de Intensidad- Tensión y potencia- tensión (305W)

1000 W/m² | 600 W/m²
800 W/m² | 400 W/m²

Corriente(A) | Potencia(W) | Voltaje (V)

Coeficiente de temperatura según Isc, Voc y Pmax

valores normalizados de Isc, Voc y Pmáx(%)

Isc
Voc
Pmax

temperatura de célula (℃)

Características mecánicas

Tipo de célula	Policristalina 156×156 mm (6 pulgadas)
Nº de células	72 (6×12)
Dimensiones	1956×992×40mm (77,01×39,05×1,57 pulgadas)
Peso	26,5 kg (58,4 libras.)
Vidrio frontal	4,0mm, alta transmisión, bajo contenido en hierro, vidrio templado
Estructura	Aleación de aluminio anodizado
Caja de conexión	Clase IP67
Cables de salida	TÜV 1×4,0 mm², Longitud: 900mm

ESPECIFICACIONES

Tipo de módulo	JKM305PP		JKM310PP		JKM315PP		JKM320PP	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Potencia nominal (Pmáx)	305Wp	226Wp	310Wp	231Wp	315Wp	235Wp	320Wp	238Wp
Tensión en el punto Pmáx-VMPP (V)	36.8V	33.6V	37.0V	33.9V	37.2V	34.3V	37.4V	34.7V
Corriente en el punto Pmáx-IMPP (A)	8.30A	6.72A	8.38A	6.81A	8.48A	6.84A	8.56A	6.86A
Tensión en circuito abierto-VOC (V)	45.6V	42.2V	45.9V	42.7V	46.2V	43.2V	46.4V	43.7V
Corriente de cortocircuito-ISC (A)	8.91A	7.22A	8.96A	7.26A	9.01A	7.29A	9.05A	7.30A
Eficiencia del módulo (%)	15.72%		15.98%		16.23%		16.49%	
Temperatura de funcionamiento (℃)	-40℃~+85℃							
Tensión máxima del sistema	1000VDC (IEC)							
VALORES máximos recomendados de los fusibles	15A							
Tolerancia de potencia nominal (%)	0~+3%							
Coeficiente de temperatura de PMAX	-0.40%/℃							
Coeficiente de temperatura de VOC	-0.30%/℃							
Coeficiente de temperatura de ISC	0.06%/℃							
TEMPERATURA operacional nominal de célula	45±2℃							

STC: Radiación 1000 W/m²   Célula módulo 25°C   AM=1.5

NOCT: Radiación 800 W/m²   Ambiente módulo 20°C   AM=1.5   Velocidad del viento 1m/s

* TOLERANCIA de medición de potencia: ± 3%

ANNEX 3

Inverter Datasheet

Growatt SPF 2000~5000TL HVM

- Integrated MPPT charge controller

- Configurable grid or solar input priority

- Optional WIFI/ GPRS remote monitoring

- Parallel for scalability

POWER
-INGO
TOMO-
RROWO

Growatt
powering tomorrow

www.ginverter.com

Datasheet	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
Battery voltage	24VDC	24VDC	48VDC	48VDC	48VDC

INVERTER OUTPUT

	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
RATED POWER	2000VA/ 2000W	3000VA/ 3000W	3000VA/ 3000W	4000VA/ 4000W	5000VA/ 5000W
Parallel Capability	No	No	No	Yes, 6 units	Yes, 6 units
AC Voltage Regulation (Battery Mode)	230VAC ± 5% @ 50/60Hz	230VAC ± 5% @ 50/60Hz	230VAC ± 5% @ 50/60Hz	230VAC ± 5% @ 50/60Hz	230VAC ± 5% @ 50/60Hz
Surge Power	4000VA	6000VA	6000VA	8000VA	10000VA
Efficiency (Peak)	93%	93%	93%	93%	93%
Waveform	Pure sine wave	Pure sine wave	Pure sine wave	Pure sine wave	Pure sine wave
Transfer Time	10 ms (For Personal Computers); 20 ms (For Home Appliances)				

SOLAR CHARGER

	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
Maximum PV Array Power	1000W	1000W	2400W	4500W	4500W
MPPT Range @ Operating Voltage	30VDC ~ 80VDC	30VDC ~ 80VDC	60VDC ~ 115VDC	60VDC ~115VDC	60VDC ~115VDC
Maximum PV Array Open Circuit Voltage	100VDC	100VDC	145VDC	145VDC	145VDC
Maximum Solar Charge Current	50A	50A	40A	80A	80A
Maximum Efficiency	97%	97%	97%	97%	97%
Standby Power Consumption	2 W	2 W	2 W	2 W	2 W

AC CHARGER

	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
Charge Current	30A	30A	15A	60A	60A
AC Input Voltage	230 VAC	230 VAC	230 VAC	230 VAC	230 VAC
Selectable Voltage Range	170-280 VAC (For Personal Computers) ; 90-280 VAC (For Home Appliances)				
Frequency Range	50Hz/60Hz (Auto sensing)	50Hz/60Hz (Auto sensing)	50Hz/60Hz (Auto sensing)	50Hz/60Hz (Auto sensing)	50Hz/60Hz (Auto sensing)

PHYSICAL

	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
Dimension (D/W/H) in mm	120/315/390	120/315/390	120/315/390	130/350/455	130/350/455
Net Weight (kgs)	7	8	8	14.5	14.5

OPERATING ENVIRONMENT

	SPF 2000TL HVM	SPF 3000TL HVM	SPF 3000TL HVM-48	SPF 4000TL HVM	SPF 5000TL HVM
Humidity	5% to 95% Relative Humidity(Non-condensing)	5% to 95% Relative Humidity(Non-condensing)	5% to 95% Relative Humidity(Non-condensing)	5% to 95% Relative Humidity(Non-condensing)	5% to 95% Relative Humidity(Non-condensing)
Operating Temperature	0℃ - 55℃	0℃ - 55℃	0℃ - 55℃	0℃ - 55℃	0℃ - 55℃
Storage Temperature	-15℃ - 60℃	-15℃ - 60℃	-15℃ - 60℃	-15℃ - 60℃	-15℃ - 60℃

ANNEX 4

Battery Datasheet

LPS SERIES-Solar Power
LPS12-230 (12V230AH)

Specification

Nominal Voltage	12V
Nominal Capacity(100HR)	230.0AH
Dimension	Length 522±3mm (20.55 inches)
	Width 240±3mm (9.45 inches)
	Container Height 218±3mm (8.58 inches)
	Total Height (with Terminal) 224±3mm (8.81 inches)
Approx Weight	Approx 65.0 Kg (143.3 lbs)
Terminal	T11
Container Material	ABS
Rated Capacity	230.0 AH/2.30A (100hr ,1.80V/cell,25^{0}C/77^{0}F)
	210.0 AH/10.5A (20hr ,1.80V/cell,25^{0}C/77^{0}F)
	200.0 AH/20.0A (10hr,1.80V/cell,25^{0}C/77^{0}F)
	174.5 AH/34.9A (5hr,1.75V/cell,25^{0}C/77^{0}F)
	121.5 AH/121.5A (1hr,1.60V/cell,25^{0}C/77^{0}F)
Max. Discharge Current	2000A (5s)
Internal Resistance	Approx 2.7mΩ
Operating Temp.Range	Discharge : -15～50^{0}C (5～122^{0}F)
	Charge : 0～40^{0}C (32～104^{0}F)
	Storage : -15～40^{0}C (5～104^{0}F)
Nominal Operating Temp. Range	25±3^{0}C (77±5^{0}F)
Cycle Use	Initial Charging Current less than 60.0A.Voltage 14.4V~15.0V at 25^{0}C(77^{0}F)Temp. Coefficient -30mV/^{0}C
Standby Use	No limit on Initial Charging Current Voltage 13.5V~13.8V at 25^{0}C(77^{0}F)Temp. Coefficient -20mV/^{0}C
Capacity affected by Temperature	40^{0}C (104^{0}F) 103%
	25^{0}C (77^{0}F) 100%
	0^{0}C (32^{0}F) 86%
Self Discharge	Leoch LPS series batteries may be stored for up to 6 months at 25^{0}C(77^{0}F) and then a freshening charge is required. For higher temperatures the time interval will be shorter.

Applications

- Green energy systems (solar, wind, hydro, etc)
- Solar power stations
- Telecommunications installations
- Measurement stations
- Pump systems
- Signal station
- Survey and Mapping system
- Emergency lighting
- Railway crossing
- Traffic lights
- Street lightening
- Lawn lamp
- Street signs
- SOS pillars
- Alarm installations
- Weekend cottage camping
- Caravans
- Boats or buoys

VdS · Intertek ETL SEMKO · UL MH26866 · ISO14001 · ISO9001 · CE · RoHS EMC tested

Constant Current Discharge (Amperes) at 25 ^{0}C (77^{0}F)

F.V/Time	15min	20min	30min	45min	1h	2h	3h	4h	5h	8h	10h	20h	48h	100h
1.85V/cell	227.5	189.0	146.8	116.3	94.1	61.3	46.3	37.9	32.0	22.4	19.2	10.2	4.58	2.25
1.80V/cell	252.2	207.9	158.4	123.5	99.2	65.2	48.8	39.7	33.6	23.5	20.0	10.5	4.65	2.30
1.75V/cell	279.8	227.7	170.4	132.0	107.0	68.3	51.5	41.5	34.9	24.2	20.4	10.7	4.73	2.32
1.70V/cell	305.7	248.7	187.2	137.9	113.0	72.0	54.0	43.2	36.3	25.1	21.1	10.9	4.78	2.35
1.65V/cell	323.7	262.5	197.2	146.4	116.9	74.5	56.0	44.7	37.6	25.7	21.5	11.2	4.87	2.39
1.60V/cell	354.8	285.0	209.6	151.7	121.5	77.6	57.9	46.1	38.9	26.4	22.0	11.5	4.95	2.41

Constant Power Discharge (Watts/cell) at 25 ^{0}C (77^{0}F)

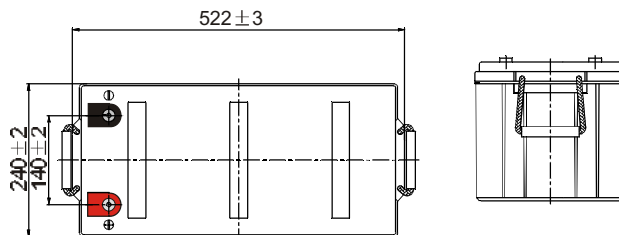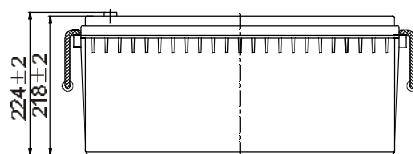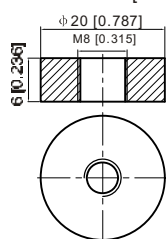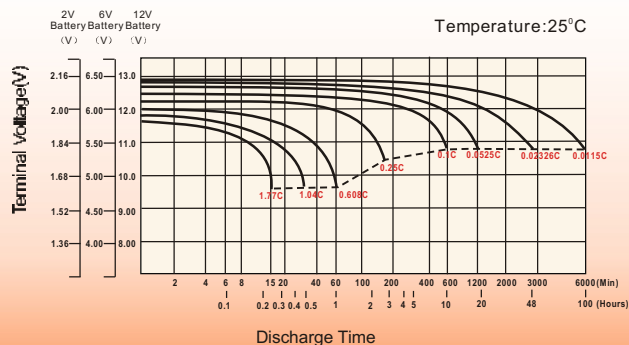| F.V/Time	15min	20min	30min	45min	1h	2h	3h	4h	5h	8h	10h	20h	48h	100h
1.85V/cell	426.8	358.2	281.3	224.7	183.0	119.7	90.6	74.4	63.1	44.4	38.1	20.3	9.16	4.51
1.80V/cell	466.8	388.2	298.9	235.7	191.3	126.4	95.0	77.6	65.9	46.4	39.7	20.9	9.28	4.59
1.75V/cell	511.5	421.2	318.9	250.7	205.4	131.9	100.0	80.8	68.2	47.7	40.5	21.3	9.41	4.62
1.70V/cell	551.1	456.6	348.4	260.8	216.2	138.7	104.6	84.1	70.9	49.5	41.8	21.7	9.51	4.68
1.65V/cell	581.4	480.1	365.5	275.7	222.9	143.1	108.2	86.8	73.2	50.7	42.7	22.2	9.67	4.74
1.60V/cell	624.3	513.7	384.2	283.0	229.6	147.9	111.1	89.1	75.4	51.9	43.5	22.7	9.83	4.78

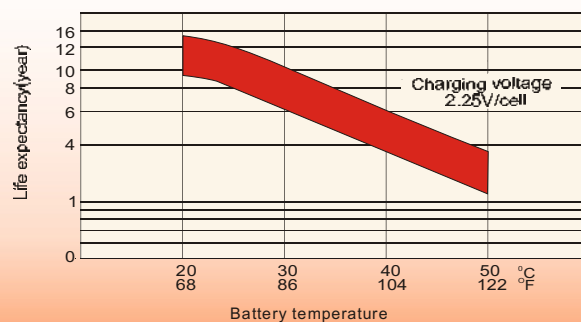Specifications subject to change without notice.
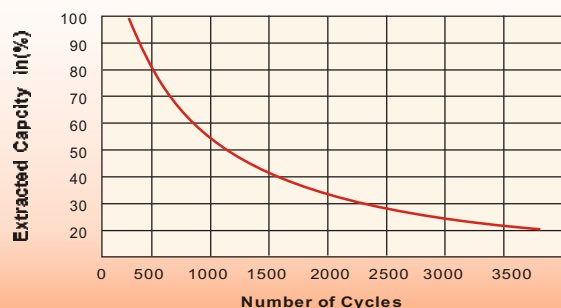
Dimensions

■ T11 Terminal
Unit: mm [inches]

φ20 [0.787]
M8 [0.315]
6 [0.236]

224±2
218±2

522±3

240±2
140±2

Discharge Characteristics

Temperature:25°C

2V 6V 12V
Battery Battery Battery
(V) (V) (V)

Terminal voltage(V)

2.16 6.50 13.0
2.00 6.00 12.0
1.84 5.50 11.0
1.68 5.00 10.0
1.52 4.50 9.00
1.36 4.00 8.00

0.1C 0.0525C 0.02326C 0.0115C
0.25C
1.77C 1.04C 0.608C

2 4 6 8 15 20 40 60 100 200 400 600 1200 2000 3000 6000 (Min)
0.1 0.2 0.3 0.4 0.5 1 2 3 4 5 10 20 48 100 (Hours)

Discharge Time

Effect of Temperature on Long Term Float Life

Life expectancy(year)

16
12
10
8
6
4
1
0

Charging voltage
2.25V/cell

20 / 68   30 / 86   40 / 104   50 / 122   °C / °F

Battery temperature

Cycle Service Life

Extracted Capcity in(%)

100
90
80
70
60
50
40
30
20

0 500 1000 1500 2000 2500 3000 3500

Number of Cycles

Self-Discharge at Different Temperatures

%Rated Capacity Available

100

75

50

25

Storage Time(months)

40°C 104°F   30°C 86°F   20°C 68°F   8°C 46°F

0 3 6 9 12 15 18 21 24 27

Charge Mode

Charging in V per cell

2.60
2.55
2.50
2.45
2.40
2.35
2.30
2.25
2.20

A
B
C

Max.charge voltage
Continous charge
Standard charge

-20 -10 0 +10 +20 +30 +40 +50

Temperature(°C)
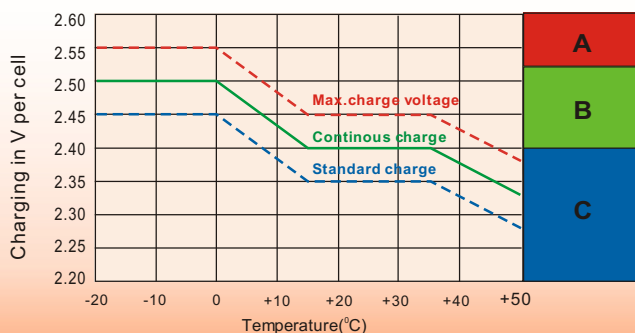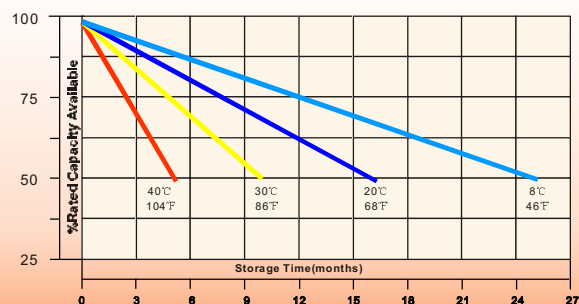
A With switch regulator (two-step controller) charge on curve max.charge voltage for max.2 hrs/day then switch over to continous charge

B Standard charge without switching

C Boost charge (Equalizing charge with external generator) charge on curve continous charge for max. 5 hrs/month, then switch over to curve Standard charge

Sales Office

ANNEX 5

PMSM Test Results and Layout

Ningbo Volcano Electric Co.,Ltd

Test report

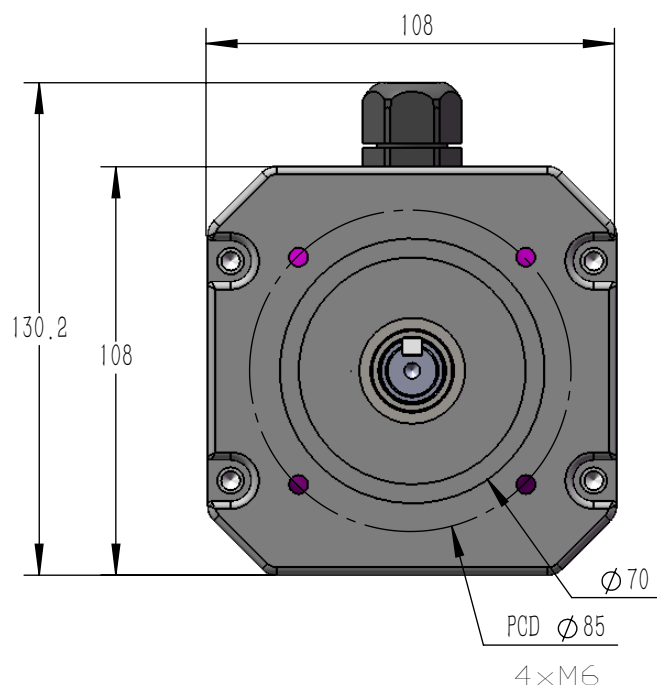| Model			V-HFM-008			Report number			001
Rated Voltage			300			Rated Current			
Rated Speed			3000			Rated output power			750
QC			test			Date			2017-8-2
Number	Serial number	Voltage V	Current A	Power IN W	Speed r/min	Torque N·m	Power out W	eff %	Rotation
1	1706001557	297.4	0.268	79.72	2998	0.002	0.479	0.60	
2	1706001557	297.5	0.348	103.4	2999	0.096	30.29	29.29	CW
3	1706001557	297.4	0.444	132.1	2999	0.115	36.26	27.45	
4	1706001557	297.4	0.595	176.8	2999	0.247	77.62	43.90	CW
5	1706001557	297.2	0.718	213.5	2999	0.388	121.8	57.05	
6	1706001557	297.3	0.934	277.7	2998	0.585	183.7	66.15	CW
7	1706001557	297.2	1.162	345.4	2998	0.799	250.8	72.61	
8	1706001557	297.3	1.436	427.0	2999	1.027	322.5	75.53	CW
9	1706001557	297.2	1.720	511.2	2999	1.298	407.7	79.75	
10	1706001557	297.2	2.031	603.7	2999	1.579	495.9	82.14	CW
11	1706001557	297.2	2.409	716.0	3000	1.874	588.7	82.22	
12	1706001557	297.2	2.732	812.0	2999	2.184	686.1	84.50	CW
13	1706001557	297.1	3.087	917.2	2999	2.499	784.7	85.55	
14	1706001557	297.1	3.519	1046	2999	2.835	890.3	85.11	CW
15	1706001557	297.0	3.904	1160	2999	3.189	1001	86.29	CW

| 1 | 2 | 3 | 4 | 5 | 6 |

172

42

10

108

130.2

108

30

2.50

∅70

PCD ∅85

4×M6

B

B

B—B
1 : 2

KEY 5x5x25

∅14

+0.20
16   0

M5▽12

ANNEX 6

Pump Datasheet

SPK 1, 2, 4 **SPK**

79. SPK

SPK 1, 2, 4

50/60 Hz, Models C, D

Coupling complete

Pos.	Kit No	495081	415060	415061	415314
	Motor/pump shaft diameter [mm]	11/12	14/12	19/12	15.8/12
	Description				NEMA
8	Coupling half	2	2	2	2
9	Screw	4	4	4	4
10	Pin	1	1	1	1

Metal terminal box

Pos.	All with MG 71/80 motor	
	Kit No	405179
	Description	
164a	Terminal box with gasket	1
164	Terminal box cover with gasket	1
166	Screw	4
175	Screw	4
176	Terminal complete	1

Rectangular flange

Pos.	Kit No	395104
	Description	
12	Flange	1
39	O-ring	1
35	Screw	4

Shaft seal

Pos.	Kit No	395008	985726	395091	985720	96765115	97730107
	Description	CVBV	AQBK	AUUV	AUUK	AQQV	AUUE
37a	Gasket	1	1	1	1	1	1
105	Shaft seal complete	1	1	1	1	1	1

Wear parts

Pos.	Kit No	395090	395089
	Number of stages	1-8	9-23
	Description		
4a	Bearing chamber	1	3
9	Coupling screw	4	4
10	Coupling pin	1	1
36	Nut	2	2
37a	Gasket	1	1
45	Neck ring	7	21
47a	Bearing ring	1	3
61	Spacer	1	1
62	Stop ring	1	1
66	Washer	1	1
66a	Washer	2	2
67	Lock nut	1	1

SPK 1, 2, 4

SPK 8 **SPK**
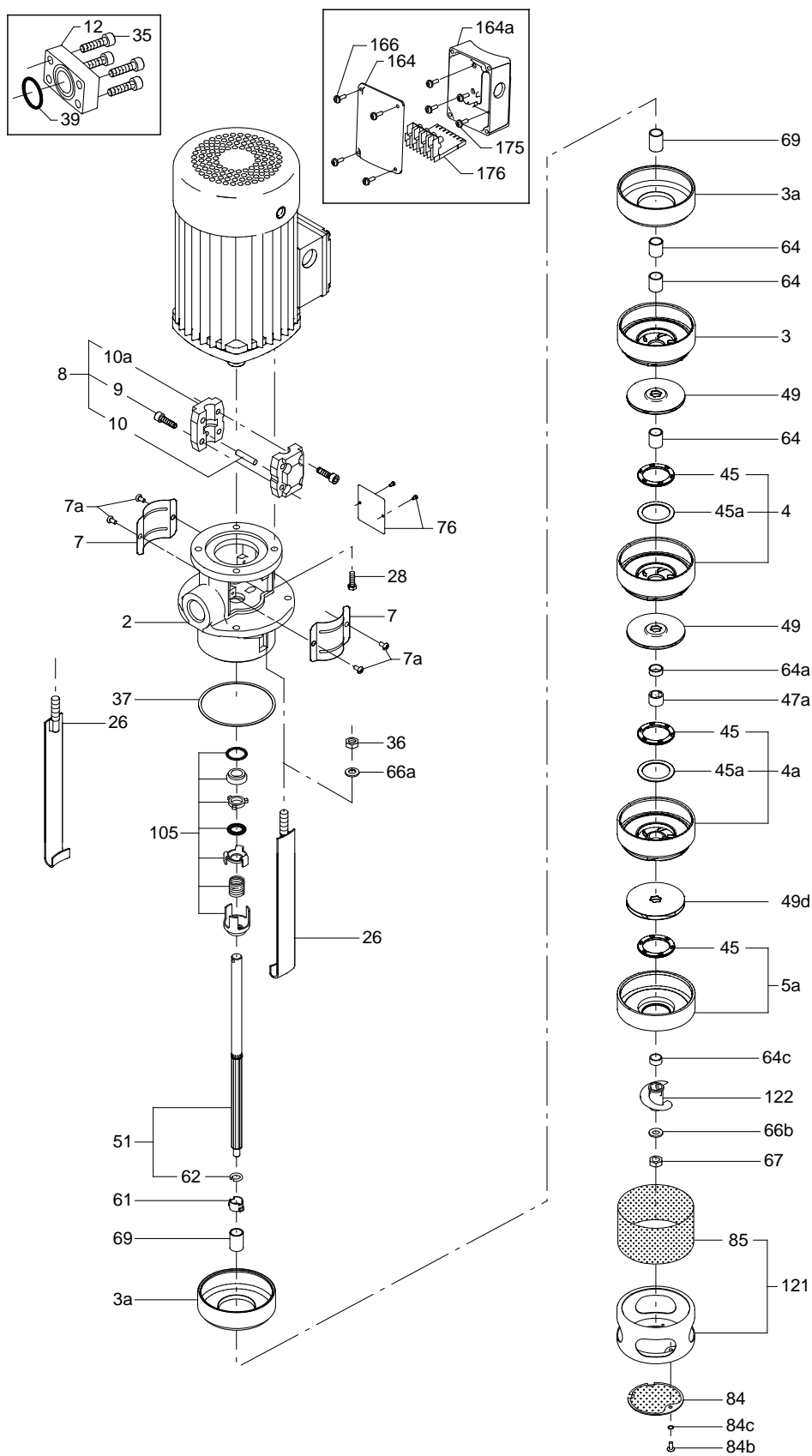
SPK 8

Coupling complete

Pos.	Kit No	415078	415079	415062	415314	415315
	Motor/pump shaft diameter [mm]	14/12	19/12	24/12	15.8/12	28.5/12
	Description				NEMA	
8	Coupling half	2	2	2	2	2
9	Screw	4	4	4	4	4
10	Pin	1	1	1	1	1

Metal terminal box

Pos.	All with MG 71/80 motor	
	Kit No	405179
	Description	
164a	Terminal box with gasket	1
164	Terminal box cover with gasket	1
166	Screw	4
175	Screw	4
176	Terminal complete	1

Rectangular flange

Pos.	Kit No	405178
	Description	
12	Counter flange	1
39	O-ring	1
35	Screw	4

Shaft seal

Pos.	Kit No	395008	985726	395091	985720	96765115	97730107
	Description	CVBV	AQBK	AUUV	AUUK	AQQV	AUUE
37a	Gasket	1	1	1	1	1	1
105	Shaft seal complete	1	1	1	1	1	1

Wear parts

| Pos.	Number of impellers	1	2-3	5	7-9	12-15	9
			incl.	excl.	excl.		
			SPK 8-5/5	SPK 8-5/5	SPK 8-12/9		SPK 8-12/9
	Only pump length L = 1005 mm			SPK 8-15/2-3			SPK 8-15/5-15
	Kit No	395093	395094	395095	395096	395097	395098
	Number of stages	1-15	2-15	7-15	7-15	12-15	12
	Description						
4a	Bearing chamber	1	1	2	2	3	3
9	Coupling screw	4	4	4	4	4	4
10	Coupling pin	1	1	1	1	1	1
36	Nut	2	2	2	2	2	2
37a	Gasket	1	1	1	1	1	1
45	Neck ring	1	4	4	7	12	13
47a	Bearing ring	1	1	2	2	3	3
61	Spacer	1	1	1	1	1	1
62	Stop ring	1	1	1	1	1	1
66	Washer	1	1	1	1	1	1
66a	Washer	2	2	2	2	2	2
67	Lock nut	1	1	1	1	1	1

SPK 8
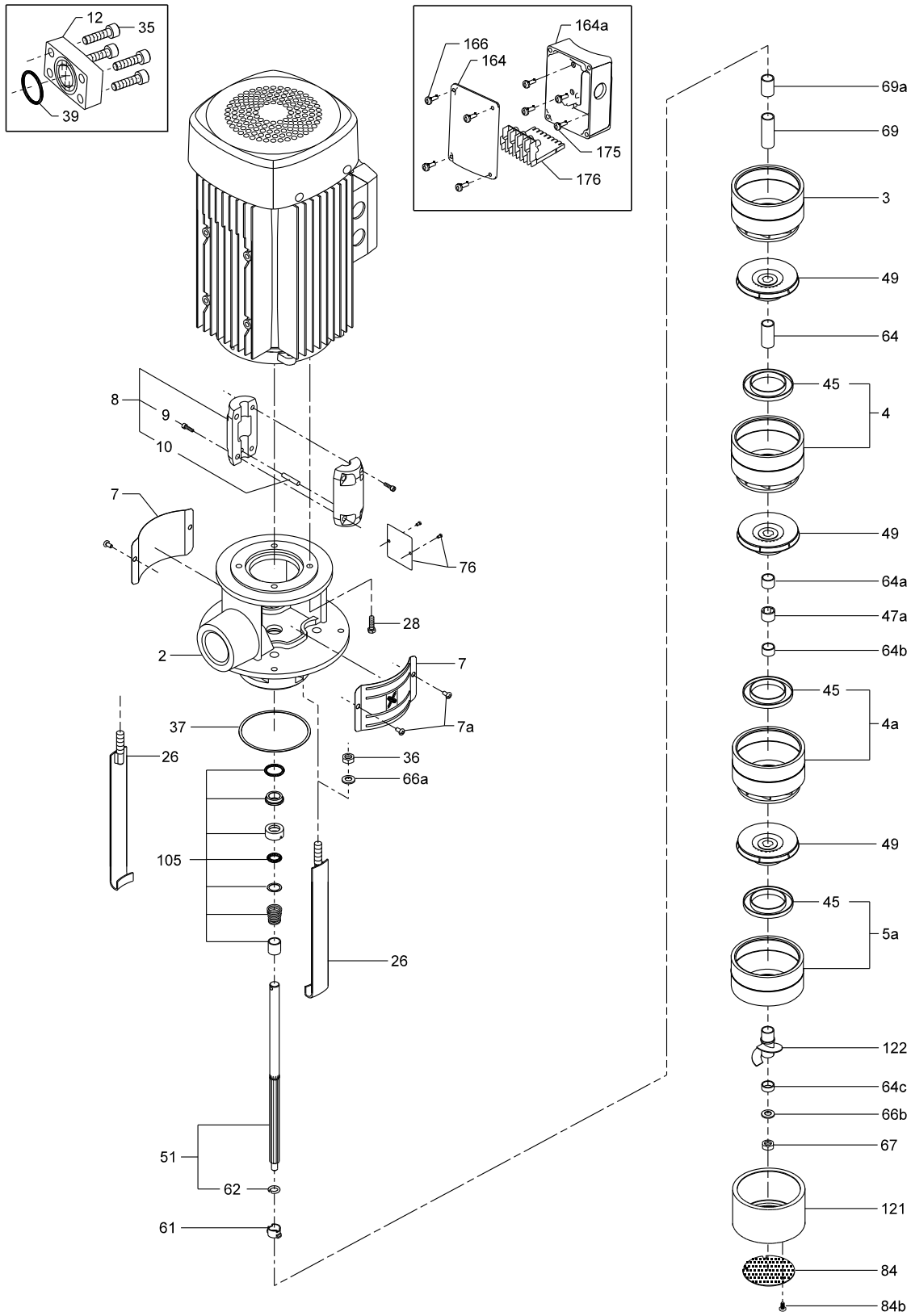
ANNEX 7

Ultrasound Datasheet

LG SONIC®MODELS

Whether you require a strong unit capable of treating very large water surfaces, or are looking for a device capable to control the algae in your garden pond efficiently, LG Sonic® offers you the best solution.

The LG Sonic® technology consists of 5 devices which have their own benefits and strengths to optimally control algae or biofilm in every application. Because of the highly advanced technique, the LG Sonic® models produce the strongest sound signals, with the lowest possible power consumption.

TECHNICAL SPECIFICATIONS:

MODELS	XXL PLUS	XL PLUS	TANK	POOL	SSS
Range Meter (Feet)	186 (600)	105 (350)	70 (230)	50 (160)	30 (100)
AC Power input 110-240V 50/60 hz	✔	✔	✔	✔	✔
DC Power input	24V	24V	24V	24V	24V
Energy consumption (W/h)	7W	5W	13W	13W	12W
Lp-Bs Technology™	YES	YES	NO	NO	NO
Dual Core Multi Frequency™	YES	YES	YES	YES	YES
Type of electric plug	Variable	Variable	Variable	Variable	Variable
Cable length meter (feet)	17 (55)	17 (55)	17 (55)	10 (30)	10 (30)
Float	Yes	Yes	Yes	Yes	Yes
Weight kg (lb)	6 (13)	6 (13)	6 (13)	6 (9)	6 (9)
Warranty	3 years	3 years	2 years	2 years	2 years
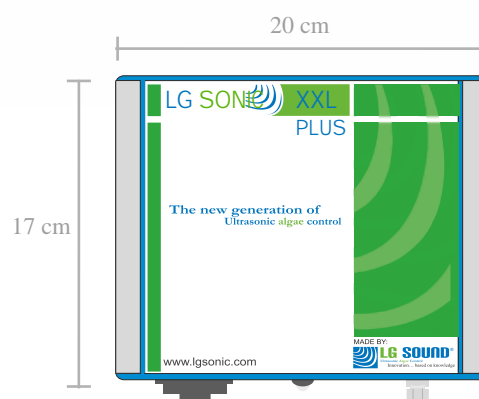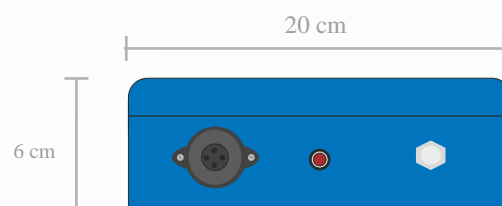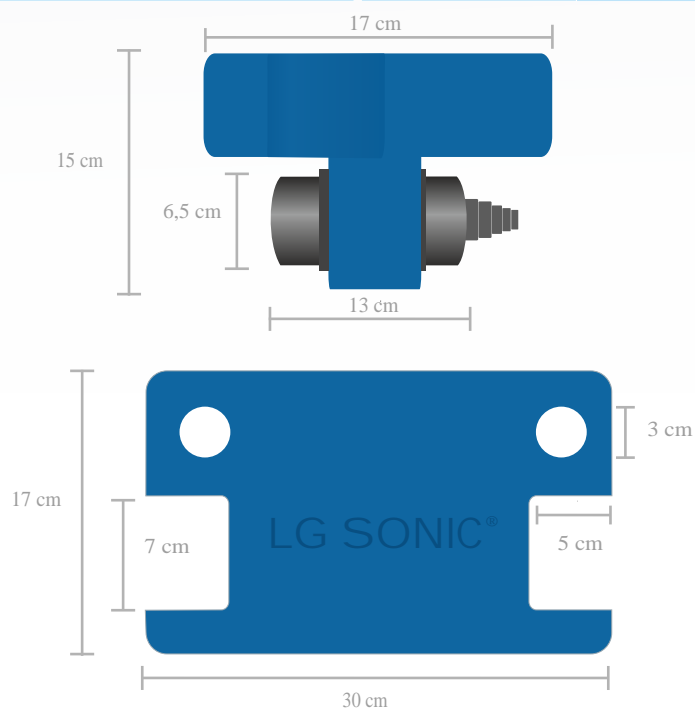
ANNEX 8

Monitoring Machine Datasheet

dataTaker

DT82EM Series 4 Data Logger

Intelligent Data Logging Products

Applications include:

Research & Development	Thermistor Arrays	Machine Down Time
Agricultural Research	Aquaculture	Pressure
Weather Stations	Structural Monitoring	Load Cells
Total Energy Monitoring	Strain Gauges	Flow
Environmental Monitoring	Process Monitoring	Vehicle Testing
Temperature Profiling	Fault Identification	GPS

*FREE Software & Technical Support

- Dual Channel Isolation Technology
- Up to 6 Analog (± 50V) sensor inputs
- 8 flexible digital terminals
- SDI-12 (multiple networks)
- Programmable Analog Output
- Integrated cellular modem
- Automatic data transfer via email or FTP
- Modbus for SCADA connection
- Web & FTP client / server
- USB memory for easy data and program transfer

Warranty: *All dataTaker Data Loggers are covered by a 3 year warranty on workmanship and parts. For further information on the dataTaker range, or for useful downloads, visit the dataTaker web site at www. datataker.com or contact your nearest dataTaker office or distributor.*

Quality Statement: *dataTaker operates a Quality Management System complying with IS09001:2008.It is dataTaker's policy to supply customers with products which are fit for their intended purpose, safe in use, perform reliably to published specification and are backed by a fast and efficient customer support service.*

Trademarks: *dataTaker is a registered trademark .*

Specifications: *dataTaker reserves the right to change product specifications at any time without notice.*
Designed and Manufactured in Australia.

*Our ability to provide free software and support is dependent on applicable export control laws (including those of the United States) and the export policy from time to time of Thermo Fisher Scientific Inc.

Versatile Measurement

Connect an array of sensors through the versatile analog and digital channels, high-speed counter inputs, phase encoder inputs and programmable serial sensor channels.

Temperature, voltage, current, 4-20mA loops, resistance, bridges, strain gauges, frequency, digital, serial and calculated measurements can all be scaled, logged and returned in engineering units or within statistical reporting.

Set up sampling, logging, alarm and control tasks to suit your own requirements while interfaces for smart sensors, GPS and other intelligent devices expand the DT82EM flexibility.

Designed For Remote Applications

The dataTaker DT82EM intelligent data logger is a fully featured low-powered logging platform with an integrated cellular modem, making it perfect for remote applications. The rugged design and wide operating temperature range of the DT82EM provides reliable operation in virtually any environment.

The DT82EM's perfect balance of performance with low-power also allows you to use a smaller solar panel without compromising on functionality.

Automatic Data Delivery

Forget travelling long distances to get your data. Utilise the DT82EM's automatic data delivery features to schedule your data to be automatically emailed to your inbox every day, week, month or other time interval.

More sophisticated systems can make use of the automatic data delivery features to send logged data to an FTP server. Alarm conditions can also trigger data delivery in addition to sending alarm messages to multiple email addresses or mobile phones.

Easy To Configure

The DT82EM is configured directly in your web browser using dataTaker's dEX graphical interface. dEX takes you through the configuration of your logger, showing you wiring diagrams and allowing you to decide – in as much or as little detail – how you want the system to work, suiting both novice or advanced users.

Using the internal modem you can even re-configure your system remotely over the internet if required.

dEX Logger Software

- Built-in software – no application to install
- Runs directly from your web browser
- Accessible by Ethernet or USB[1] connection
- Intuitive graphical interface
- Easy-to-use configuration editor
- Access live and historical data
- View data as charts, mimics and tables

What is dEX?

dEX is an intuitive graphical interface that allows you to configure your data logger, view real-time data in mimics, trend charts or tables and retrieve your historical data for analysis.

dEX runs directly from your web browser and can be accessed either locally or remotely, anywhere that a TCP/IP connection is available including worldwide over the Internet. You can use any of the logger's built-in communications ports to view dEX including Ethernet, USB and RS-232.

Easy configuration

The dEX configuration editor allows you to view, edit and save logger configurations in an easy-to-use Windows Explorer style user interface.
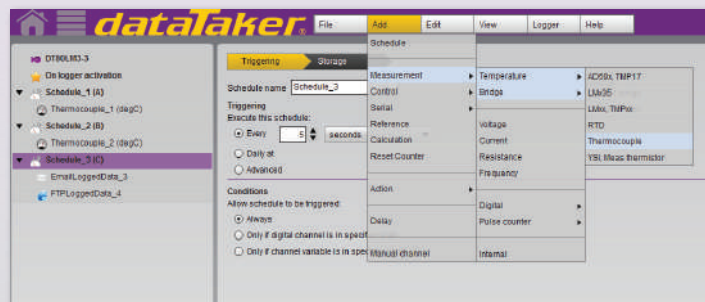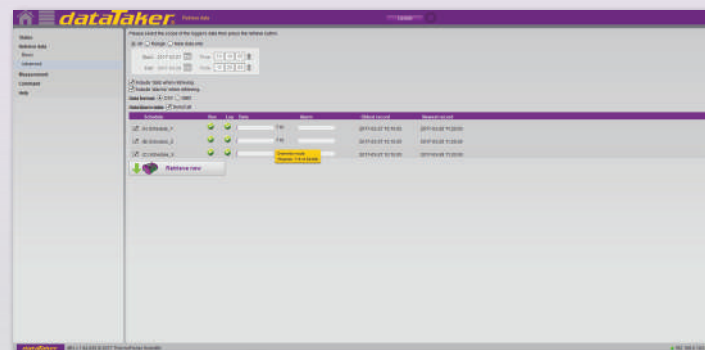

Real-time monitoring

dEX displays real-time sensor measurements, calculations and diagnostic information using mimics, tables and trend charts.

Data retrieval

dEX allows you to retrieve your data at the click of a mouse button. Just select either All, Range or New Data Only.

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[1] USB port equipped models only.

dEX Logger Software

Browser-based solution

dEX comes pre-installed on every logger in the DT80 range[2]. The software loads in your web browser so there is no need to install cumbersome applications on your computer. Being browser-based, dEX is cross-platform and will work on all major operating systems including Windows, Mac and Linux. To simplify it even further, dEX starts automatically in your default web browser when you connect to your logger using a USB cable[1].

Data that is compatible with your applicatons

Logged data is ready to import into common spreadsheet and data processing applications such as Excel for further analysis and reporting. Data can be saved to your computer in comma separated (.CSV) format or our proprietary binary (.DBD) format.

Command window

The command window provides a terminal interface which allows the built-in command language of the logger to be used. Macro buttons allow common commands to be sent on a button press.

Configuration editor

The configuration editor allows you to view, edit and save logger configurations in an easy-to-use Windows Explorer style user interface. Tree view of configuration allows definition of measurement schedules and measurements.

Wiring diagrams show available wiring configurations for each sensor type. Configuration can be stored and retrieved on either the logger or a local computer.

Independent — Platinum RTD (3 wire)

Independent — Platinum RTD (4 wire)
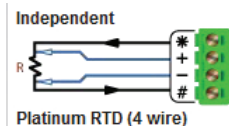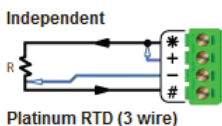
Channel list

Displays name, value, units, alarm state, time stamp and logging state for each measurement.

Customisation of the application

The menu options, mimics panels and mimics can be added or removed to suit novice or advanced users. The color and brand name images within dEX can be customised to match corporate requirements or for personal preference.

Mimics are organised into panels which can be modified to highlight custom alarm conditions or data grouping. Mimics include dials, bar graphs, thermometers etc. Real-time chart recorder mimic allows you to view trends and historical data over a custom time/date range. Up to 16 mimics can be displayed on up to 5 mimic pages (default is 1 page of 6 mimics).

Minimum system requirements

- Web Browser (tested with): Internet Explorer V7 and above, Firefox, Safari & Google Chrome
- TCP/IP connection
- Adobe flash player 10 or higher
- Screen resolution of 1024 x 768

Chart Recorder Mimic

Real-time trending for sensors, calculations or other data. Supports up-to 5 traces per chart and up-to 2 Y-axes. Backfills with historical data stored in logger.

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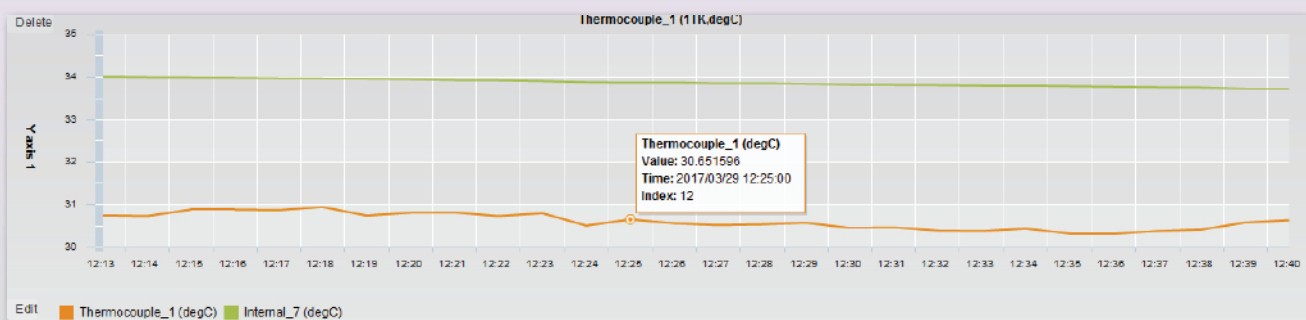
[2] dEX operates on all DT80 Series 2, Series 3 and Series 4 except Series 1.

Technical Specifications

Analog Channels

2 analog input channels
Each channel is independent and supports: one isolated 3-wire or 4-wire input, or two isolated 2-wire inputs, or three common referenced 2-wire inputs.
The following maximums apply.
- 2-wire with common reference terminal: 6
- 2-wire isolated: 4
- 3- and 4-wire isolated: 2

Fundamental Input Ranges
The fundamental inputs that the DT82EM can measure are voltage, current, resistance and frequency. All other measurements are derived from these.

Sampling
Integrates over 50/60Hz line period for accuracy and noise rejection
Maximum sample speed: 40Hz
Effective resolution: 18 bits
Linearity: 0.01%
Common mode rejection: >90dB
Line series mode rejection: >35dB

Inputs
Inter-Channel Isolation: 100V (relay switching)
Analog Section Isolation: 100V (opto-isolated)
Input impedance: 160KΩ, >100MΩ
Common mode range: ±3.5V or ±55V (attenuator on/ off)

Sensor Excitation (Supply)
Analog channels:
- selectable 2μA, 213μA or 2.5mA precision current source
- 4.5V voltage source
- switched external supply

General Purpose: Switchable 12V/5V regulated supply for powering sensors & accessories (max 150mA).

Analog Output
Isolated programmable 16-bit DAC: voltage 0-10V or current 0-24mA

Analog Sensors

Supports a wide range of sensors including, but not limited to, those listed below. A wide range of sensor scaling and linearising facilities including polynomials, expressions and functions.

Thermocouples
Types: B, C, D, E, G, J, K, N, R, S, T
Calibration standard: ITS-90

RTDs
Materials supported: Pt, Ni, Cu
Resistance range: 10Ω to 1MΩ

Thermistors
Types: YSI 400xx Series, other types*
Resistance range: up to1MΩ
* Other thermistor types are supported by thermistor scaling and calculated channels.

Monolithic Temperature Sensors
Types supported: LM34 - 60, AD590, 592, TMPxx, LM135, 235, 335

Strain Gauge and Bridge Sensors
Configurations: ¼, ½, & full bridge
Excitation: voltage or current

4-20mA Current Loop
Internal 100Ω shunt or external shunt resistor

Digital Channels

Digital Input/Outputs
4 bi-directional channels
Input Type: 4 logic level (max 20/30V)
Output Type: 3 with open drain FET(max: 30V, 100mA)
1 with logic output

Relay Output
1 latching relay, contacts (max: 30Vdc, 1A)

Counter Channels

Low Speed Counters
4 counters shared with digital inputs.
Low speed counters do not function in sleep mode.
Size: 32 bit Max Count rate: 10 Hz

Dedicated Counter Inputs
4 high speed inputs
Size: 32 bit Max Count rate: 100 kHz
Input type:
- 2 logic level inputs (max ±30V),
- 2 sensitive inputs (100mV) for magnetic pickups (max ±10V)

Serial Channels

SDI-12
1 SDI-12 inputs, shared with digital channels. Each input can support multiple SDI-12 sensors.

Generic Serial Sensor
Flexible options to allow data to be logged from a wide range of smart sensors and data streams.
Available ports: Host RS232 Port*
Baud rate: 300 to 115,200
*If used as a Serial Sensor channel then the Host Port is not available for other communications.

Calculated Channels
Combine values from analog, digital and serial sensors using expressions involving variables and functions.
Functions: An extensive range of Arithmetic, Trigonometric, Relational, Logical and Statistical functions are available.

Alarms
Condition: high, low, within range and outside range
Delay: optional time period for alarm response
Actions: set digital outputs, transmit message, execute any dataTaker command.

Scheduling of Data Acquisition
Number of schedules: 11
Schedule rates: 10ms to days

Data Storage

Internal Store
Capacity: 128MB (approx 10,000,000 data points)
Larger storage available refer to technical support.
Removable USB store device (optional accessory)
Types: compatible with USB 1.1 or USB 2.0 drives, e.g. Flash drive.
Capacity: approx. 90,000 data points per megabyte.

Communication Interfaces

Ethernet Port
Interface: 10BaseT (10Mbps)
Protocol: TCP/IP, Modbus Slave

Network (TCP/IP) Services
Uses Ethernet and/or Host RS232 (PPP) ports

Command Interface
Access the ASCII command interface of the DT82EM via TCP/IP

Web Server
Access current data and status from any web browser. Custom pages can be defined. Download data in CSV format. Command interface window. Define mimic displays.

Modbus Server (slave)
Access current data and status from any Modbus client (e.g. SCADA system)

FTP Server
Access logged data from any FTP client or web browser

FTP Client
Automatically upload logged data direct to an FTP server

System

Display and Keypad
Type: LCD, 2 line by 16 characters, backlight.
Display Functions: channel data, alarms, system status.
Keypad: 6 keys for scrolling and function execution.
Status LEDs: 4 for sample, disk, attention and power.

Firmware Upgrade
Via: Ethernet or USB memory.

Real Time Clock
Normal resolution: 200 μs
Accuracy: ±1 min/year (0°C to 40°C),
±4 min/year (-40°C to 70°C)

Power Supply
External voltage range: 10 to 30Vdc
Peak Power: 12W (12Vdc 1A)

Average power Consumption
Using 12Vdc external power source

Sampling Speed	Average Power
1 second	1350 mW
5 seconds	500 mW
30 seconds	135 mW
5 minutes	70 mW
1 hour	60 mW

Integrated Cellular Modem

Features
Alarms: Send email or SMS messages
Data: Send data to an email address or FTP server
Remote access: Connect to dEX or Command interface
SIM interface: SIM Socket (1.8V/3V)

Networks and Frequencies
Interfaces: EDGE, GPRS, GSM, WCDMA, HSUPA, HSDPA
EDGE/GPRS/GSM Freq: 850/900/1800/1900 MHz
WCDMA/HSUPA/HSDPA Freq: 850/1900/2100 MHz

Physical and Environment
Construction: Powder coated zinc and anodized aluminum.
Dimensions: 180 x 137 x 65mm
Weight: 900g (3kg shipping)
Temperature range:–45°C to 70°C*
Humidity: 85% RH, non-condensing
*reduced battery life and LCD operation outside range −15°C to 50°C

Accessories Included
Resource CD: includes software, video training and user manual.
Comms cable: USB cable
Line adaptor: 110/240Vac to 15Vdc, 800mA

For full technical specifications download the user's manual from our website www.datataker.com