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Grau Enginyeria en Tecnologies Industrials

Design of a Solar Microgrid for the Community of Mpaga, Gabon based on its social and economic context.

MEMÒRIA

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ABSTRACT

Energetic isolation is one of the most wide-spread problems amongst rural communities in many regions of the planet. Solar off-grid installations stand out as one of the best solutions to help these communities obtain access to electricity. The project consists in the design of a solar micro-grid for the community of Mpaga in Gabon, managed and funded by ESPACE AFRIQUE FONDATION. The aim has been to design and dimension a viable project that considers all the phases and factors involved in the planning, development and operation of a solar energy system in a remote area. These combine social, economic, infrastructural, logistical and technical considerations and requirements.

The first step is to find a suitable community upon which the study will be based. After a period of contacting many organisations in Africa, a collaboration agreement was reached with Engineers Without Borders in Gabon to carry out this project in the community of Mpaga, which is built around a boarding school. The first section of the thesis consisted in the study of the community with the aim of understanding its energy needs. These included researching on its location, access, number of inhabitants, villagers' habits, facilities, infrastructure, solar resources, etc...

A load profile has been determined based on the devices and loads present in Mpaga and the villager's lifestyle. For the design and dimensioning of the electrical installation, the general structure of the circuit has first been determined, only to proceed to the election of each electrical component based on cost-effectiveness and performance indicators. Several energy-system optimizers have been useful to carry out the dimensioning of several components in the site. Acquisition, maintenance and replacement costs have been considered for every device. Other less obvious factors have proven to have a relevant impact on the total cost of the project, such as container ship transportation from Barcelona's port to Mpaga or installation costs.

The creation of a local institution in charge of managing the operation and maintenance of the site, as well as other less technical activities such as tariff design and collection or dealing with overconsuming villagers has proven to be an essential task if the installation is to operate successfully.

Finally, after undergoing a 25-year long cashflow predictive analysis, the project has been confirmed as economically viable, and therefore the recommendation for ESPACE AFRIQUE is to proceed with the installation of the designed microgrid.

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0 INTRODUCTION

0.1 Purpose and scope of the thesis

The main purpose of this thesis is to carry out the design and optimisation of a solar-powered microgrid for a rural and isolated community. The microgrid should help the community improve their daily life in a sustainable way, while at the same time reduce their actual or future carbon foot-print. Most of the technical study of this project will focus on the design and optimisation of the solar microgrid, and it would be technically possible to carry it out based on a virtual community with an estimated load distribution and energy needs. However, it was decided that finding a real suitable community to study, with all the extra effort this implies, was essential for several reasons. Firstly, and most important, it could help the inhabitants of a real and existing community improve their lives and commodities. But secondly, it was thought that having to adapt to real constraints (physical, economical, geographical...) would give the thesis a much more realistic perspective.

In order to find a suitable community to study, many African institutions and NGOs were contacted. At first, it seemed that the project would be able to succeed alongside Engineers Without Borders Uganda, but once the conversation was at a considerably advanced stage, and due to funding and budget issues with the foundation, the collaboration came to an end.

After this, we were forced to restart contacting Institutions, and in the end found a suitable partner with Engineers Without Borders Gabon. They were currently starting a project alongside 'Foundation Espace Afrique' in a village named Mpaga, regarding the rehabilitation of their health-centre and a restructuration of their waste management (see annex document). Both parties concluded that an energetic solution was also necessary for the village, and that they would be pleased if this study was focused in the Mpaga Community.

As for the scope of the thesis, it will be divided in three main phases. Firstly, the community must be studied and analysed to have a clear picture of their energy needs. This phase's tasks basically consist in carrying out a thorough research and conducting interviews with locals from the community to gather the necessary information. Secondly, the proper design of the installation will be carried out. Once this phase has been successfully completed, several energetic optimisers will be used in order to help determine the most cost-effective distribution and dimension for some of the components in the site.

0.2 Definitions, acronyms and abbreviations

Item	Definition
A	Amps
AC	Alternating Current
Ah	Amp-Hour
CC	Charge Controller
CPU	Central Processing Unit
CS	Canadian Solar
DC	Direct Current
DC-DC	Direct Current to Direct Current Converter
EWB	Engineers Without Borders
Gen.	Generator
I-V	Intensity-Voltage
IRR	Intern Rate Return
IMF	International Monetary Fund
LA	Lead Acid
LED	Light Emitting Diode
MPPT	Maximum Power Point Tracker
NPV	Net Present Value
O&M	Order and Maintenance
PG	Port-Gentile
PV	Photovoltaic
TV	Tele Vision
USD	United States Dollar
V	Volts

Table 1. Definitions, acronyms and abbreviations.

1 COMMUNITY STUDY

1.1 General Information

1.1.1 Location

The village of Mpaga stands close to the west coast of Gabon, close to the economical capital of Port-Gentil, which is its closest city and 104km away from Mpaga. The community stands close to the Ogooue River, and adjoins the 'Wonga Wongue National Park', although this is actually more of a Presidential Natural Reserve than a public national park.

The community can only be accessed by boat, from the city of Port Gentil or from Lambaréné, another town from Gabon. The following images show the community's location on a world and country scale.

Figure 1. Africa Political Map

Figure 2. Gabon Political Map

Figure 3. Mpaga Satellite Image

1.1.2 Mpaga's inhabitants

Mpaga is home to 300 villagers, 200 of whom are students living in the Mpaga Boarding School, entirely funded by Espace Afrique. Therefore, it can be said that Education Service is the main activity in Mpaga. However, besides education, agriculture is probably the most important economic activity. Also, there are a few fishermen in the village. Also, besides farming and teaching, the Foundation employs a few cooks to prepare the student's food.

1.2 Community Facilities and Infrastructure

1.2.1 Access

The only way to access the village of Mpaga is by boat, from the city of Port-Gentile or Lambére. From Port-Gentile it can take from 2 hours and a half up to 5 hours to get there, depending on the boat. On average, the cost of getting to Mpaga by a motored-pirogue is of 440$ USD (fuel expenses). However, to transport the solar panels a bigger boat would be needed, so the real transportation cost to Mpaga can't be provided by EWB.

The village has no proper roads. To get from the decks to the village some sandy pathways can be used. There is currently one van in the village that could help with the transportation from the river to the village.

The following image shows the mentioned pathway.

Figure 4. Pathway to Mpaga

1.2.2 Water Sources and Waste Management

The nearest water-source to the village is the Ogooué River. The villagers, however, use the water from two water towers in the village. This water towers lack of a float system, so they tend to overflow when it rains heavily. People in Mpaga wash themselves with water buckets, as the towers cannot provide enough pressure. It still needs to be discussed with the foundation, but the new solar installation would be definitely able to power a new water pump.

Figure 5. Ogooué River, Close to Mpaga

1.2.3 Village Facilities

The village is mainly based on the structure built around a large boarding school and the medical centre which is being repaired by the Foundation Espace Afrique. The following table provides more information on the village's facilities, which are to be considered as plausible electrical load points.

Service	Description
Education	Primary School, Secondary School, Teacher and Students accommodation and School kitchen.
Health	One medical centre, currently has problems with bats living inside.
Water	Two water towers, lacking float system.
Waste Management	A pit has been dug. Waste is burnt in the pit. Currently can't get rid of resistant packages such as cans, glass bottles, etc.
Security	Existing policemen houses, although only one is occupied. The rest are abandoned.
Construction Space	There is plenty of space to install the PVs. The terrain is sandy, but not aprubt.
Energy	Two diesel generators
Other	The village also has a market, and some shops and bars

Table 2. Village's Facilities

The following images show the village's school and police houses.

Figure 6. Policemen Houses

Figure 7. Primary and Secondary School

1.3 Energetic Situation

1.3.1 Current situation

Mpaga village has two diesel generators totally funded by Espace Afrique as their only source of energy. The generators have a capacity of 150kVA and 80kVA respectively, with a power factor of 0.8

The fuel needed to supply these generators is also funded by Espace Afrique, and it is actually a concern to the Foundation, as it is very expensive to transport the fuel to Mpaga. Since the village is hardly accessible and far away from the nearest city, the annual cost of diesel is around 80,000$ USD. For this reason, the construction of a solar self-sufficient microgrid would strongly help the community become more economically independent and less fragile, as well as economically positive for Espace Afrique on the mid-long term.

The fact the actual cost of their energy source is so high is a positive factor when it comes to the microgrid design, as it ensures that the installation will be profitable on the long term. Once the microgrid is operating, the fuel costs will significantly decrease. The Foundation had these fuel costs planned for the following years, so these fuel savings will compute as income or profit when the economic balance is done.

1.3.2 Energy Usage

The energy consumption in Mpaga is basically used for lighting, powering fans and food conservation. It has been proposed to the foundation, that given that a big investment will be done to switch from diesel generators to solar energy, they might as well improve their energetic supply.

Cooking in Mpaga is done in a traditional way (firewood) and no energy is used for water supply as there is currently no water pump.

2 MICROGRID DESIGN

2.1 Community Current Situation

2.1.1 Economic Situation and Power Supply

As mentioned before, the community of Mpaga's energy supply relies on the energy provided by two diesel generators. Diesel generators are usually employed in communities such as Mpaga due to the fact that they are usually pretty straightforward to deploy and are relatively reliable, besides usually being an economically viable option. However, they also carry some obvious disadvantages when compared to renewable sources, which would be the cost of the fuel to supply the generator as well as the emissions it produces. Moreover, getting the fuel to Mpaga is extremely difficult due to the fact it can only be accessed by boat and after a several hour-long trip, which substantially adds to the cost of maintaining these generators in operation.

These generators can deliver 150kVA and 80kVA of power respectively, but keeping the generators operating has an annual cost of 78,000$ USD. As mentioned before, when studying the economic performance of replacing the current energy system for a solar microgrid, these fuel expenses will be considered as profits, since ESPACE AFRIQUE will no longer have to pay for them. Therefore, to calculate some economic viability indicators such as pay-back time, an annual income of 78,000$ will be considered in the cases where the diesel supply is totally replaced.

Another advantage of replacing the current electrical system is that most of the installation and cabling costs can be neglected, as these are already installed in the community of Mpaga, although some adaptation will be necessary.

2.1.2 Energy Solar Resources

The community of Mpaga lies in the riverbed of Ogooué River, Gabon. To calculate the amount of energy that can be obtained by means of solar PVs, the radiation data for these coordinates is considered.

Latitude	Longitude
0º 56' 57'' S	9º 26' 66'' E

Table 3. Community's Coordinates

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KWh/m²/d	4.95	5.14	5.14	4.86	4.68	4.56	4.59	4.67	4.81	4.54	4.24	4.64

Table 4. Monthly Solar Irradiance in Mpaga

It can be appreciated from the table above that solar irradiance in the region of Mpaga remains considerably steady throughout the whole year. This will be an advantage when it comes to the grid's design, as we will be able to rely on a similar amount of solar energy for each month. The annual average solar irradiance is **4.74 KWh/m²/day.**

2.2 Microgrid Structure and Dimensioning

2.2.1 Microgrid General Structure

The microgrid to be designed for the community of Mpaga will be formed by the following solar energy production and management components and a backup diesel generator used at specific times to lower the total cost of the installation. These diesel generators are already operating in the community, but the whole aim of the project is to lower their usage as much as possible so Mpaga can be more sustainable, but most importantly, more independent. Besides the generator, the PV modules, DC combiner box, MPPT trackers, charge controllers, battery bank, inverter, loads, circuit breakers and the AC service panel are the installation's main components. Figure below illustrates this structure.

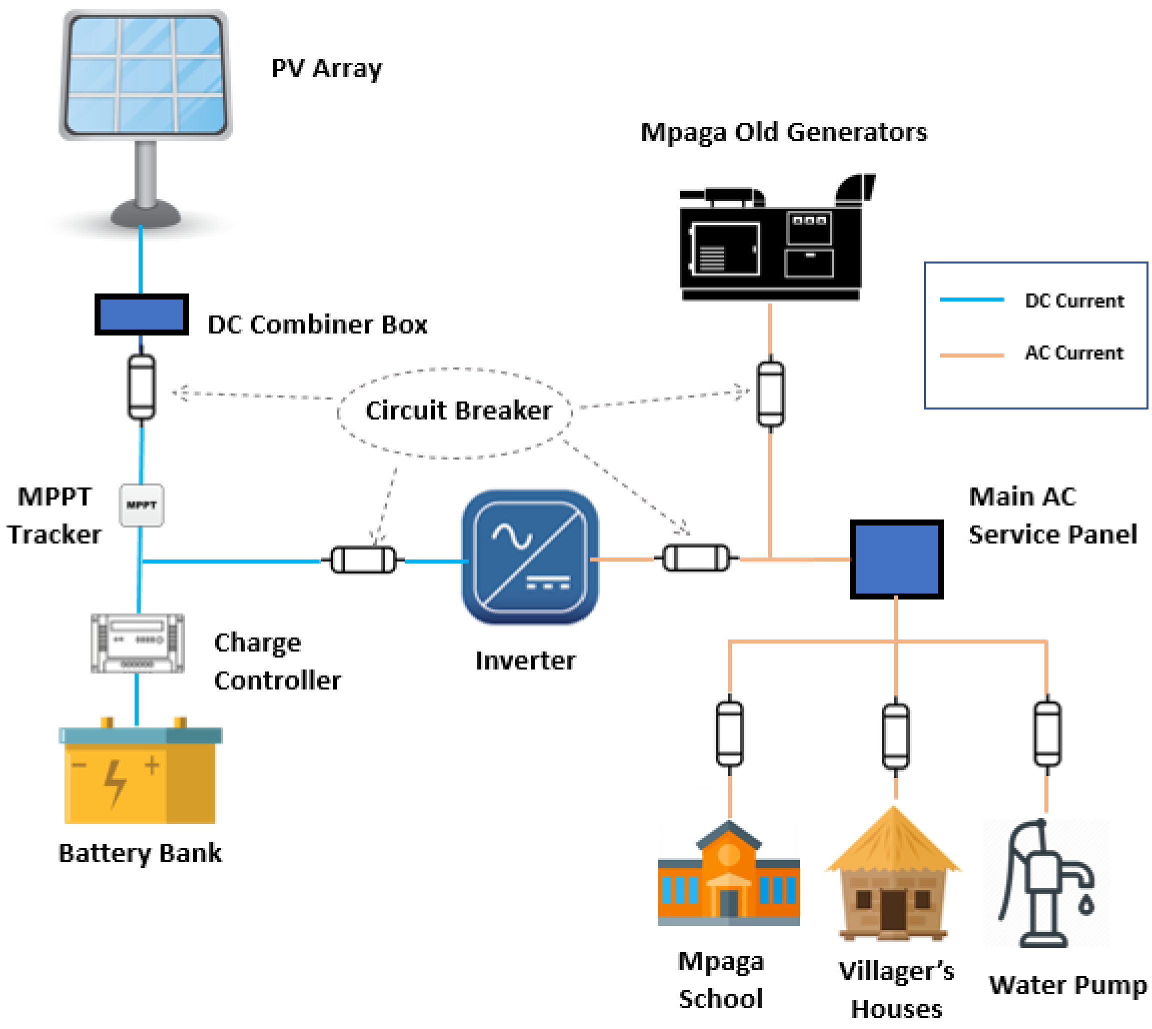

Figure 8. Mpaga Solar Off-Grid Structure

Each PV module array is formed of one or more strings. A DC combiner box is used to wire together the cables from each string. After this, an MPPT tracker is used to optimize the power output coming from the solar panels. A charge controller stands between the MPPT tracker and the battery bank, and will act as a DC-DC converter to charge the batteries in the most suitable way. An inverter will be in charge of converting the DC current into AC current. The diesel generator may will supply the grid with power at specific times. Circuit Breakers will be placed between all the components for safety reasons.

2.2.2 Load

The first step in order to begin the actual dimensioning of the site, is to determine the load it will have to serve. To do that, some estimations have been done based on the information provided by EWB Gabon and ESPACE AFRIQUE foundation. These estimations are based in the facilities that were listed in the reports, the number of villagers, social activities and daily lifestyle. Firstly, the village has been separated in different groups based on the nature of the loads. The following table provides a list with all the devices that have been considered, as well as their power consumption and maximum operating quantity.

Group	Device / Load	Max. Operating Quantity	Nominal Power (W)
School Classes	Old Large Refrigerator	4	300
	Old Large Freezer	2	450
	Fluorescent Lights	25	40
	Filament Lights	16	100
	Ceiling Fans	72	80
	Floor Fans	12	280
	Video Player	2	250
	Kettle	2	750
	Radio Cassete	3	80
Student's Rooms	Filament Lights	80	100
	Floor Fan	10	290
Bars (3)	Old Large Refrigerator	3	350
	Old Large Freezer	1	450
	Filament Lights	21	100
	Ceiling Fans	24	80
	Radio Cassete	3	120
	TV	3	400
	Kettle Usage	3	750
Markets (2)	Old Industrial Freezer	3	450
	Old Industrial Freezer	2	450
	Fluorescent Lights	50	40
	Filament Lights	18	100
	Floor Fan	6	280
Housing	Filament Lights	150	100
	TV	15	250
	Phone Charger	120	4
Other	Water Pump	1	13400
	Police Radio	3	100
	Small Refrigerator (Health Cente	1	150

Table 5. List of Mpaga Loads

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Once the list of loads and their power consumption has been determined, it is necessary to know their operating hours, so a minimum energy production (kwh) can be approximated. The following table shows the operating hours of each load on an average day. These distributions have been estimated based on a natural community behaviour pattern. If further on it is determined that a different distribution of the demand hours could result more convenient, some limitations or demand hour modifications can be done, as the whole energy installation will be operated, managed and paid for by the foundation.

<table>
<tr><th></th><th>Time[h]</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
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<tr><td>TV</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">3750</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Police Radios</td><td></td><td></td><td></td><td></td><td colspan="13">300</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Health Center Refrigerator</td><td colspan="24">150</td></tr>
<tr><td rowspan="3">TOTAL</td><td>Fix (kW)</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td></tr>
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<tr><td>Total (kW)</td><td>8,9</td><td>8,9</td><td>8,9</td><td>6</td><td>10</td><td>28</td><td>36</td><td>38</td><td>37</td><td>34</td><td>23</td><td>21</td><td>31</td><td>45</td><td>46</td><td>49</td><td>44</td><td>35</td><td>16</td><td>17</td><td>12</td><td>10</td><td>10</td><td>9,38</td></tr>
</table>

Table 6. Operating Hours for each load

If the total estimated power output the installation must provide is represented on a bar graph, the following information is obtained.

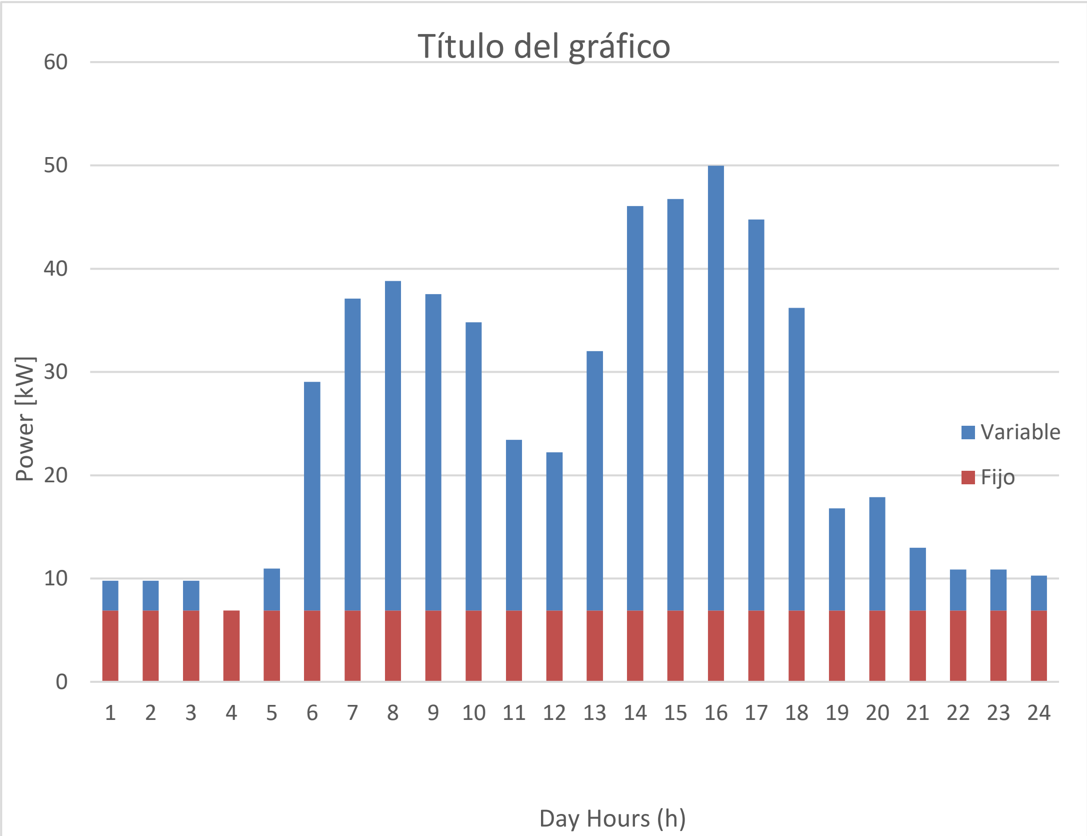

Figure 9. Hourly power consumption

It is easily observed that Mpaga's consumption shows two clear peak times. The first one is around noon, and is due to the school's and other businesses' busiest hours. The next peak hour is approximately at 8pm. This is due to the fact that at this time of the day the sun has already set but practically all villagers are still active, this resulting in a high demand of lighting. Also, during these leisure hours, villagers usually gather to watch some of the old TVs or radios, or spend some time at the bars. The first peak happens during hours where solar incidence is almost at its highest point. The second peak time, however, happens during hours where the sun has already set. This may have significant consequences in the minimum storage capacity the installation shall require.

Another factor that will considerably increase the number of necessary batteries and storage capacity is the constant consumption of the freezers and refrigerators. These loads are consuming all the hours in a day, and this means that they are consuming during many non-solar-active hours. For these reason, a deeper insight has been considered for this load. Given the fact that temperatures decrease during night hours, and that the freezers' and refrigerator's doors are not opened (this results in heat entering the refrigerator, therefore an increase in power consumption in order to compensate the entrance of heat) during night hours, it was thought that power during night-hours may be slightly lower than during solar irradiant intervals.

To verify this hypothesis, commercial refrigerators power consumption rates were investigated. The following graph shows an hourly average of energy consumption during an entire day of a typical commercial refrigerator. Although the refrigerators in Mpaga are larger and older, they work in an analogous way, so the information obtained by studying this graph can be considered in Mpaga too.

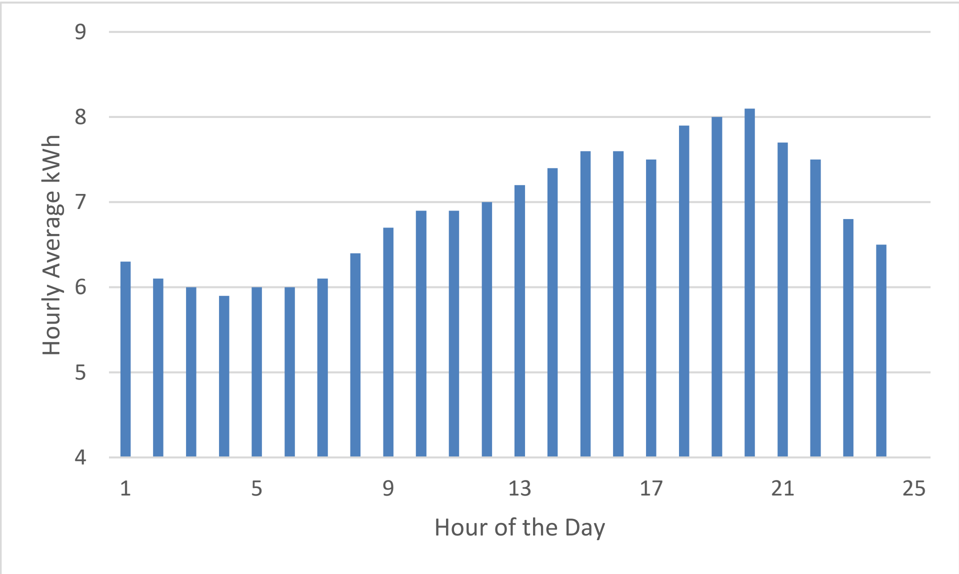

Figure 10.Refrigerator Hourly Consumption

It is clearly observed that the hypothesis is confirmed, given that during night hours the consumption is about 25 % lower than during other hours of the day. The peak in consumption is due to the fact that usually between 6pm and 9pm families have dinner and open and close the refrigerators more frequently. To a lesser extent, it is also more common for warm food and beverages to be introduced in the refrigerators and this interval of hours.

If we apply a 25% decrease to the power consumption of refrigerators and freezers during night hours (01am-06am), the consumption table is as follows:

<table>
<tr><td></td><td>Time[h]</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
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<tr><td>Ceiling Fans</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">5760</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Radio Cassete</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>240</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">tudent's Roor</td><td>Room Ilumination</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">8000</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Kettle Usage</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">250</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Markets (2)</td><td>Refrigerators</td><td colspan="3">1013</td><td colspan="17">1350</td><td colspan="4">1013</td></tr>
<tr><td>Freezers</td><td colspan="3">675</td><td colspan="17">900</td><td colspan="4">675</td></tr>
<tr><td>Market Ilumination</td><td></td><td></td><td></td><td></td><td></td><td colspan="5">1000</td><td></td><td></td><td colspan="4">1800</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Police Radios</td><td></td><td></td><td></td><td></td><td colspan="13">300</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Health Center Refrigerator</td><td colspan="24">150</td></tr>
<tr><td rowspan="3">TOTAL</td><td>Fix (kW)</td><td>4,54</td><td>4,5</td><td>5</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>5</td><td>5</td><td>5</td><td>4,54</td></tr>
<tr><td>Variable (kW)</td><td>2,9</td><td>2,9</td><td>3</td><td>0</td><td>4</td><td>22</td><td>30</td><td>32</td><td>31</td><td>28</td><td>17</td><td>15</td><td>25</td><td>39</td><td>40</td><td>43</td><td>38</td><td>29</td><td>10</td><td>11</td><td>6</td><td>4</td><td>4</td><td>3,38</td></tr>
<tr><td>Total (kW)</td><td>7,44</td><td>7,4</td><td>7</td><td>6</td><td>10</td><td>28</td><td>36</td><td>38</td><td>37</td><td>34</td><td>23</td><td>21</td><td>31</td><td>45</td><td>46</td><td>49</td><td>44</td><td>35</td><td>16</td><td>17</td><td>11</td><td>9</td><td>9</td><td>7,92</td></tr>
</table>

Table 7. Load Operating Hours considering Refrigerators power rates.

When proceeding with the calculations and optimisation, **a 15% day-to-day v**ariation will be considered.

2.2.3 Fuel Price

Having a back-up diesel generator can substantially lower the cost of off-grid renewable installations by producing energy at very specific moments. This basically allows the system to operate with far less energy storing capacity, which is usually one of the main costs. However, in order to determine whether it would be beneficial to use the generator at certain times during the day, it is essential to know the fuel's price. Usually this would not be an issue, as diesel is widely commercialised in most regions, but as we've mentioned before, the diesel has to be brought to Mpaga by boat, after a several hour-long trip. For this reason, it becomes slightly more complex to determine the cost in $/litre of fuel. EWB were not able to provide us this information, but they did confirm their monthly expenses in diesel, which is roughly 6500$. To determine the fuel's price, we must firstly calculate each day's fuel consumption in. Once we have this information, we know how many litres the generator is consuming per month, and we can therefore obtain an approximate value of the fuel's price by dividing the total fuel costs by the monthly fuel consumption.

The following table, which shows fuel consumption rates for different loads in a 120kW diesel generator, is used to calculate the amount of diesel litres consumed per day based in the estimated power consumption.

Load (%)	0	25	50	75	100
Fuel consumption (litres/hour)	0	10,8	18,6	25,9	33,7

Table 8. Fuel Consumption for a 120kW Diesel Generator

ETSEIB

For each hour of the day, a constant power has been estimated. To obtain the fuel consumption for each hourly interval, the following graph has been used. The equation of the tendency line will allow us to estimate each hour's specific consumption with an acceptable error margin.

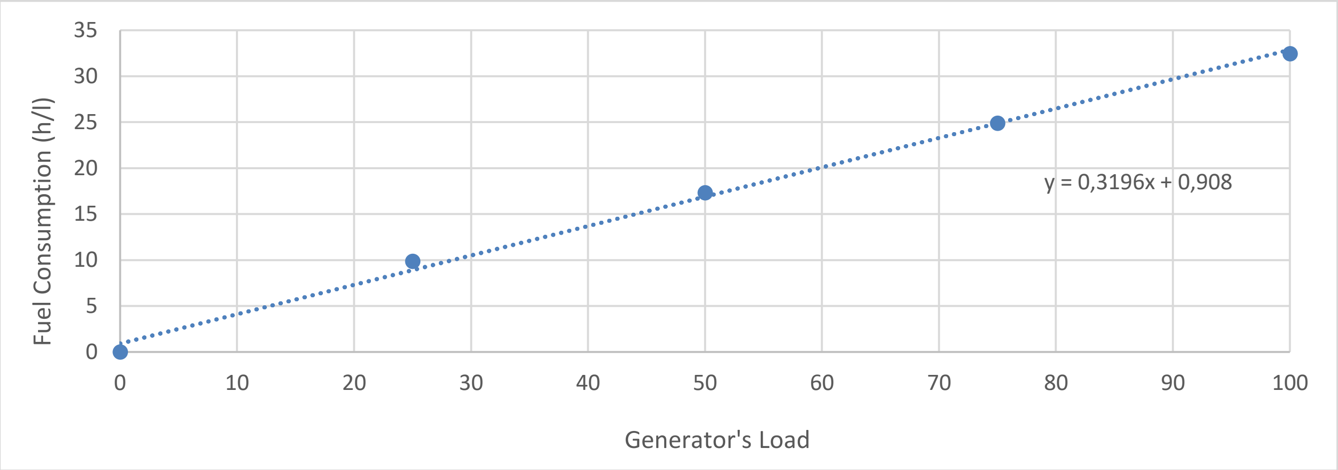

Figure 11. Fuel Consumption based on Load

With the equation provided by the tendency line, and assuming it will carry a small error percentage, we obtain the following table.

Hour (h)	Power Load (kW	Generator Load (%)	Fuel Consumption (litres/h)
5	9,80	8,17	3,60
6	9,80	8,17	3,60
7	9,80	8,17	3,60
8	6,90	5,75	2,81
9	10,95	9,13	3,92
10	29,03	24,19	8,89
11	37,10	30,91	11,11
12	38,80	32,33	11,58
13	37,54	31,28	11,23
14	34,80	29,00	10,48
15	23,42	19,51	7,35
16	22,22	18,51	7,02
17	32,02	26,68	9,71
18	46,06	38,38	13,57
19	46,76	38,97	13,77
20	49,96	41,63	14,65
21	44,76	37,30	13,22
22	36,21	30,18	10,87
23	16,80	14,00	5,53
24	17,88	14,90	5,83
1	12,98	10,82	4,48
2	10,88	9,07	3,90
3	10,88	9,07	3,90
4	10,28	8,57	3,74
		TOTAL Daily (litres)	**188,33**
		TOTAl Monthly (litres)	**5650,01**

Table 9. Mpaga's Fuel Consumption

If we now divide the monthly fuel costs by the monthly fuel consumption, we obtain an approximated value of the fuel's price:

$$\frac{6500\,\$}{month} \cdot \frac{month}{5650\ litres} = \mathbf{1,15}\ \$/\ \boldsymbol{litre}$$

When optimizing the energy production's distribution, this value will be used as an input value.

2.2.4 Solar Panels

2.2.4.1 General Information

As a basic introduction, all photovoltaic cells consist of two or more thin layers of semi-conducting material. These semi-conductor is usually silicon, and when exposed to light or solar radiation, it generates electrical charges that can be conducted as DC using metal contacts. This is at a considerably small scale and produces little energy. For these reason, cells are usually connected to form strings. When strings are again connected to one another, usually behind a glass protector, a module or panel is formed. Using several panels is usually enough for systems intended to power a single house-hold or a small building. However, for the Mpaga project, it is very likely that many solar arrays will be necessary, given the dimension of the project. This basic information applies to every type of solar cell. However, based on their silicon or other material composition, several types of widely commercialised solar PVs are found, and each of them offers different performances and properties. In the following chapter these types will be analysed and the most suitable type for the Mpaga project will be chosen.

2.2.4.2 Types of PVs

When it comes to choosing which type of solar PV is going to be used in Mpaga, the following PV types must be considered:

Monocrystalline silicon PV panels: Made using cells which are sliced from a single cylindrical crystal of silicon. These are the most efficient panels, as its efficiency rates range between 14%-19%. However, its manufacturing process is complicated, which results in slightly higher prices than other technologies.

Polycrystalline Silicon PV panels: These are made from an ingot of melted and recrystallized silicon. These ingots are then cut into thin slices and assembled into cells. Given the manufacturing process is simpler, that are usually slightly cheaper than monocrystalline cells. However, its efficiency tends to be slightly lower, with efficiencies ranging around 12%-15%.

Thick-film silicon PV panels: These PVs are built as a variation of the polycrystalline technology. In this case, silicon is continuously deposited onto a material acting as a base. This gives a fine, grained appearance. As the other technologies, they are usually encapsulated in transparent insulating polymers.

Thin-film silicon PV panels: This amorphous silicon cells are made as silicon is deposited in a thin homogenous layer onto a substrate. Amorphous silicon allows deposition in a very wide range of substrates (rigid, flexible…). For this reason, they are very useful when it comes to designing PVs for curved surfaces. Also, its manufacturing price is lower than other technologies. Thin-filmed PVs, however, have efficiencies far lower than the other technologies, with values ranging from 4%-7%.

Although this list does include the most typically commercialised technologies for producing PV panels, there are two technologies that stand out from the rest when it comes to microgrid design and dimensioning. These are monocrystalline PVs and polycrystalline PVs. The following table helps us compare these two technologies:

Property	Monocrystalline	Polycrystalline
Efficiency	14%-19%	12%-15%
Aesthetics	Black Hue, Uniform	Blue heterogenous colour
Cost	More Expensive	Cheaper
Longevity	+25 years	+25 years

Table 10. PV Technology comparison

It can be observed from the table above that these diverse types of technology both have advantages and disadvantages. In some situations, highly space-restricted projects will strongly prioritise efficiency, needing less surface area per kW installed. However, in projects where space is not a constraint, cheaper technologies may be a better solution. Aesthetics can also play a key role, but it is usually more relevant in small-scale housing projects, where rooftop appearance may be important to the customers. In Mpaga, there is plenty of space for placing the PVs, but transportation will be a relevant factor to consider. For this reason, efficiency may still be considered as a prime factor.

2.2.4.3 Solar Panel Election

To choose the best panel for the solar installation in Mpaga, several factors have been considered. The two most important factors have been efficiency and cost as in $/W installed. Different models for some of the most commercialised manufacturers have been analysed, as show in the following table and graph.

	Model	Efficiency	$/W	Max Volts (V)	Max Current (A)
Canadian Solar	CS6K-275K	16,80%	0,70	35,4	8,94
	CS6K-290MS	17,71%	0,68	32,1	9,05
	MaxPower CS6U-325P	16,72%	0,61	34,3	8,74
Hanwha	QCells Q.Plus L-G4.2 340W	17,10%	0,65	37,63	9,03
	Q.PLUS L-G4.2 325W	16,30%	0,84	36,7	8,85
	Q.PRO L 305 305W	15,50%	0,95	36	8,54
LG	LG335S2W-G4 MonoX 335W	17,10%	0,83	37,5	8,94
Jinko Solar	JKM350M-72-V 350W	16,40%	0,70	37,4	8,94
	JKM330PP-72-V 330W	17,01%	0,62	37,8	8,74
	JKM325PP-72-V 325W	16,75%	0,61	37,6	8,66
JA Solar	JAP6 72-345 345W	17,80%	0,74	38,39	9,54
	JAP6 72-325/4BB 325W	16,77%	0,61	37,49	8,67

Table 11. Costs and Efficiency of PV Models

It can be easily observed that all the efficiency values range from 15%-19%, although this table includes both mono and polycrystalline technologies. However, given the dimension of the installation will be considerably larger than a house-hold scale project, apparently small variations can still make a significant difference in the total cost and performance of the site. The following graphs allows an easier interpretation of these results.

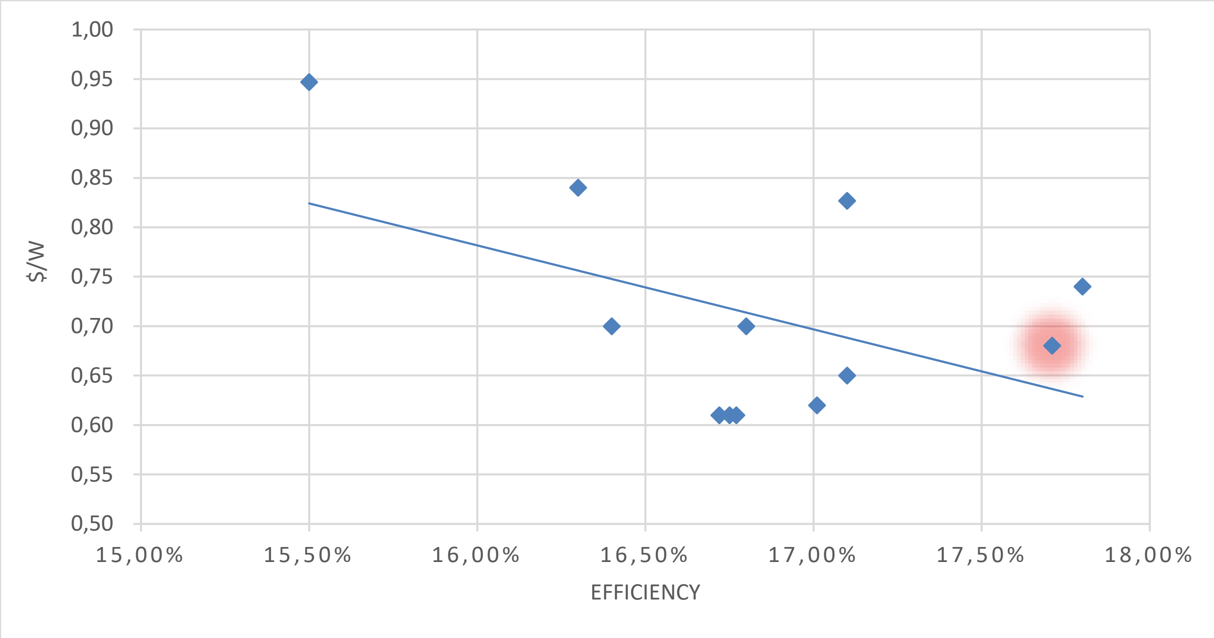

Figure 12. Scatter Plot of PV model's Cost and Efficiency

After analysing these results, one of the models has been chosen to be the model upon which the solar installation is based. This model is highlighted in the graph, and is the model **Canadian Solar CS6K-290MS 290W Mono.**

The following tables provides more detailed information on the module's mechanical and electrical characteristics and have been obtained from the official Datasheet for this model offered by Canadian Solar.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline, 6 inch
Cell Arrangement	60 (6×10)
Dimensions	1650×992×40 mm (65.0×39.1×1.57 in)
Weight	18.2 kg (40.1 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP67, 3 diodes
Cable	4 mm² (IEC) or 4 mm² & 12 AWG 1000 V (UL), 1000 mm (39.4 in)
Connectors	T4 (IEC / UL)
Standard Packaging	26 pieces, 520 kg (1146.4 lbs) (quantity & weight per pallet)
Module Pieces per Container	728 pieces (40' HQ)

Table 12. CS6K.290MS Mechanical Data

Additionally, the following table provides some extra information on the electrical characteristics of the PV.

ELECTRICAL DATA / STC*

CS6K	290MS	295MS
Nominal Max. Power (Pmax)	290 W	295 W
Opt. Operating Voltage (Vmp)	32.1 V	32.3 V
Opt. Operating Current (Imp)	9.05 A	9.14 A
Open Circuit Voltage (Voc)	39.3 V	39.5 V
Short Circuit Current (Isc)	9.67 A	9.75 A
Module Efficiency	17.72 %	18.02 %
Operating Temperature	-40°C ~ +85°C	
Max. System Voltage	1000 V (IEC) or 1000 V (UL)	
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)	
Max. Series Fuse Rating	15 A	
Application Classification	Class A	
Power Tolerance	0 ~ + 5 W	

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

Table 13. CS6K.290MS Electrical Data

As it can be seen below Table 12, these performances indicators are under a solar irradiance of 1000W/m^2 and a cell temperature of 25ºC. These will most probably not be the operating conditions for Mpaga during most of the hours. Temperature effects and hourly solar irradiance considerations will be dealt with in further chapters.

2.2.4.4 Solar Panels' Location

One of the most typical constraints when it comes to solar installations can be the space required to install the solar panels. In Mpaga, however, this shouldn't be a very restrictive condition. When this matter was discussed with members of the foundation, they assured there was plenty of space for solar panel installation. The area they had thought that may be suitable for this task was near the school.

This spot has been studied and it does seem a convenient area for solar installation. Firstly, it is an open, shade-free spacious area. The solar panels will not be shaded at any time during the day, so no shading factor must be considered. The terrain in that area is relatively sandy, so building the racks for the panel installation should not be an issue. Also, as it is close the community's main load, this will reduce wiring and installation costs.

The following image should give a simple view of the community's distribution and the areas where the PV panels could be located.

Figure 13. Mpaga Map to Show Possible PV ubications

2.2.4.5 Temperature Considerations

Solar Panels are power tested at 25 ºC, and the standard values provided by the manufacturer in the datasheet are obtained when the installation performs at this temperature. Although it may seem strange, temperature has a negative effect on solar panel's efficiency. This effect is usually measured or scaled by a P max temperature coefficient. Other temperature coefficients affect the Open Circuit Voltage or the short circuit current.

The following table, provided too by the manufacturer, shows the three temperature coefficients mentioned above:

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.39 % / °C
Temperature Coefficient (Voc)	-0.30 % / °C
Temperature Coefficient (Isc)	0.053 % / °C
Nominal Operating Cell Temperature	45±2 °C

Table 14. CS6K.290MS Temperature Coefficients

The following graphs show the effect these temperature coefficients have in the efficiency and Current-Voltage performances of the panel. In the following chapters and optimisations, however, the effect on efficiency will stand as a more relevant parameter.

The following graph is also provided by the manufacturer. However, for other calculations, an optimiser named *PVSyst* will be employed. This optimizer also has a data-base with performance indicators for almost every solar-model. The information provided by the manufacturer and the optimiser will be compared in order to be sure the optimizer bases its calculations in official data.

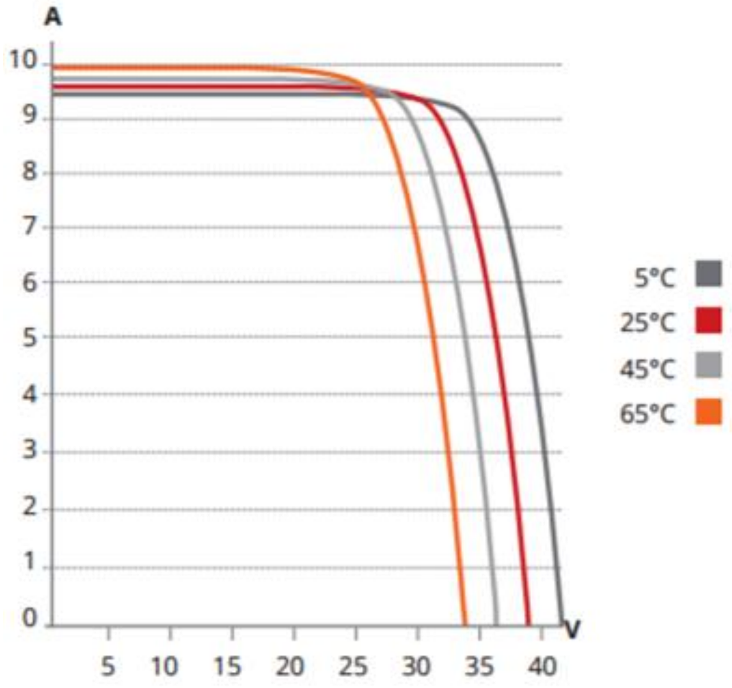

Figure 14. CS6K.290MS I-V Curve based on Cell Temperature provided by manufacturer

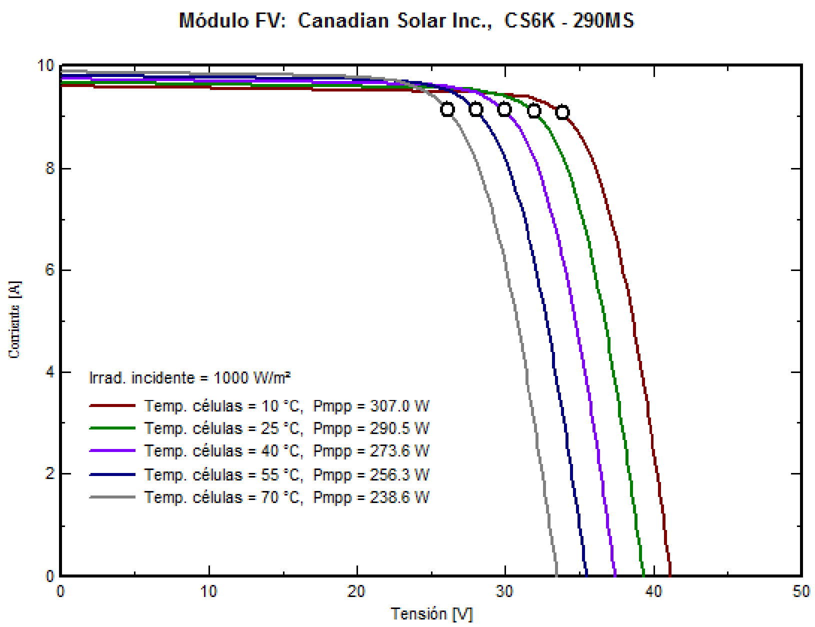

Figure 15. I-V Curve based on Cell Temperature provided by PVSyst Optimiser

Although it may not be a surprise, it is confirmed that the optimizer uses the manufacturer's official data to proceed with its calculations.

The following table is probably even more relevant, and shows the effect of cell temperature on the panels efficiency.

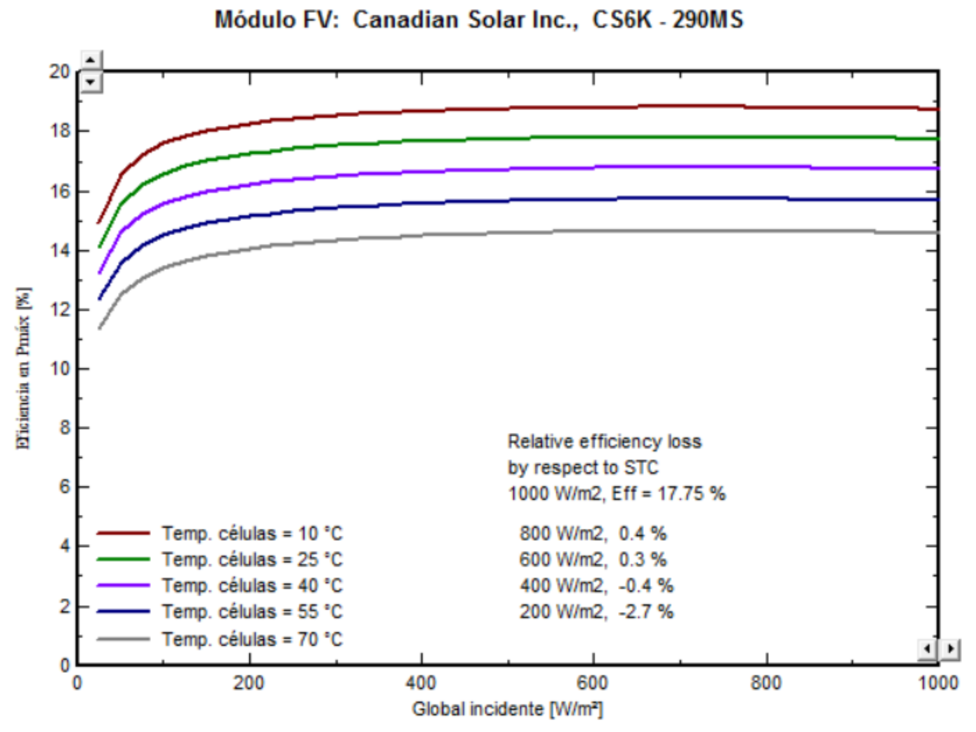

Figure 16. Temperature effect on efficiency

The negative effect of temperature on a cell's efficiency is clearly observed. For instance while in a winter sunny day in Europe (10ºC) , the solar panel could be performing at a higher efficiency than the one stated in the manufacturer's datasheet, in a typical day in Mpaga (40ºC cell operating temperature) , the solar panels will be probably performing at values ranging around 16%.

Must be noted that the cell's operating temperature, upon which this calculations and corrections are performed, will most probably not be the same as the location's ambience temperature.

2.2.5 Charge Controller

Solar charge controllers are in charge of managing the power that goes into the battery bank from the solar panels. It ensures that the deep cycle batteries do not overcharge during high irradiance periods (usually around noon), or that the power does not run backwards from the batteries to the solar panels during night time. They also typically include a DC-DC converter to ensure batteries are charged at their optimal voltage and current for every instant.

Also, some charge controllers come with a previous MPPT (Max. Power Point Tracking) technology. These devices are used to at every given time, and using different algorithms depending on the model or technology, set the PV panels in the most optimal point of the I-V curve based on power production. Systems with MPPT technology are require a higher initial investment, but are profitable on the long term, as they significantly increase the efficiency of solar installations.

From an even simpler point of view, the MPPT will ensure the PV arrays are producing as much power as possible under any condition (mainly solar irradiance variations). Afterwards, DC-DC converter in the charge controller will convert the current from the solar PV arrays so it matches the voltage of the battery bank. This results in a considerable decrease in lost power from the PV panels to the batteries.

The chosen model is the **LEONICS SOLARCOM SPM series** model **24070**. This charge controller includes MPPT, and will PV array voltage input ranging from 170 to 220V. It can work under a maximum current of 70A and withhold a maximum power of 13,7 kW. Additionally, it is meant to charge battery banks of 240V nominal voltage. To obtain these PV input requirements, the solar arrays and strings will have to be specifically designed for this purpose. Some other relevant features of this model are as follows:

- **Charge Controller Features**
  - MPPT Tracker
  - Advanced microprocessor control.
  - High efficiency (>98%).
  - 3-Step charging to provide quick and safe charging.
  - Easily understandable LED and LCD display.
  - Overload, overcharge and undercharge alarm and protection.
  - Power and event data log.

- **Array Calculations:**

  - **String Size:** The desired input for the MMPT will limit the string size. Each of the chosen panels delivers a maximum of 32,1V. To obtain a voltage in the desired range, 6 or 7 panels should be wired in series for each string. Given that 32,1 is the maximum voltage, it will be safer to make the strings seven panels long. This way, 224V would be obtained in optimal conditions. The dimensioning will ensure that the operating voltage of the string falls in the range of the Charge controller when conditions are not optimal

  - **Number of Strings:** The number of strings is limited by the maximum current the charge controller can take. In this case, the controller can take up to 70A. For this reason, given the chosen solar panel can provide up to 9,05A, six strings per charger is a sensible choice to ensure the limit will not be overpassed.

The following image represents the array mentioned above for each of the MPPT charge controllers in Mpaga's installation.

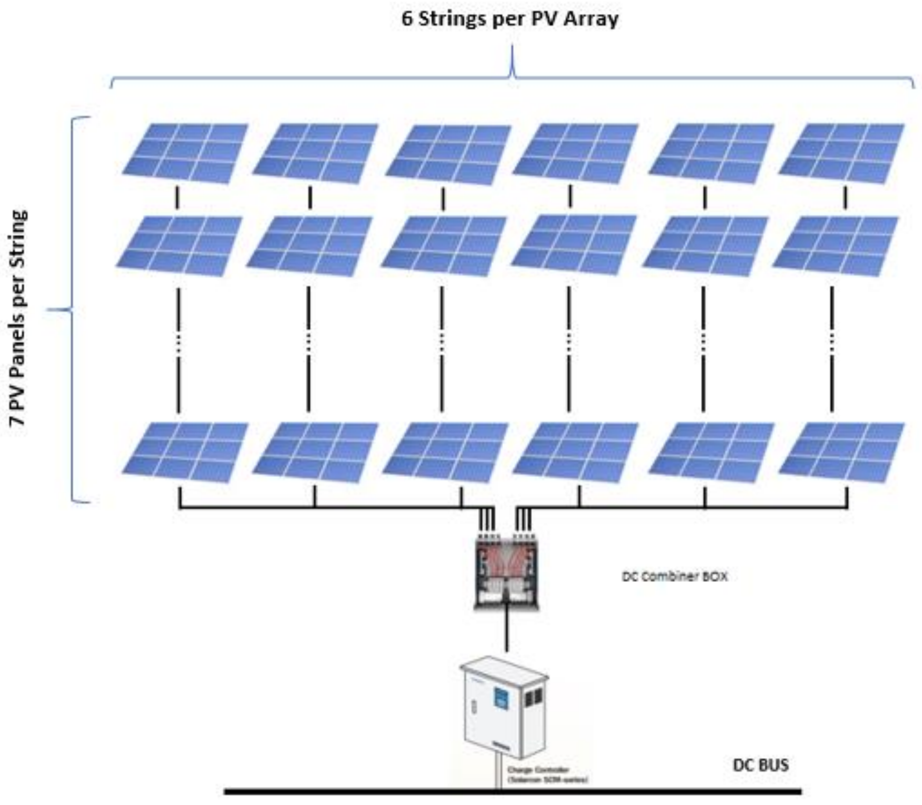

Figure 17. Diagram of Designed PV Array with LEONICS CC

The following images show the Charge controller in its version for rack mounting (wall mounting is mainly designed for rooftop installations) and the main specifications of the charge controller. To see full datasheet, go to Annex.

Figure 18. LEONICS SOLARCOM SPM CC prepared for Rack Mounting

SPECIFICATIONS

Wall Mount/Tower Model	SCM-12035	SCM-12070	SCM-120105	SCM-120140	SCM-24035	SCM-24070	SCM-240105	SCM-240140
Rack Mount Model	SCM-12035/RM	SCM-12070/RM	SCM-120105/RM		SCM-24035/RM	SCM-24070/RM	SCM-240105/RM	SCM-240140/RM
INPUT (Configuration of PV in series within these voltage range)								
V_{mp} of PV*	85 - 110 Vdc				170 - 220 Vdc			
Tracking voltage range	48 - 110 Vdc				96 - 220 Vdc			
V_{oc} of PV*	< 138Vdc				< 276 Vdc			
Maximum current	35 A	70 A	105 A	140 A	35 A	70 A	105 A	140 A
Maximum PV power**	3.4 kWp	6.88 kWp	10.3 kWp	13.7 kWp	6.88 kWp	13.7 kWp	20.6 kWp	27.5 kWp
OUTPUT (at 25°C)								
Nominal battery voltage	120 Vdc				240 Vdc			
Boost charging voltage	130.0 - 150.0 Vdc				260.0 - 300.0 Vdc			
Float charging voltage	120.0 - 140.0 Vdc				240.0 - 280.0 Vdc			
Low voltage alarm	100.0 - 120.0 Vdc				200.0 - 240.0 Vdc			
Low voltage cut off (signal)	99.0 - 119.0 Vdc				198.0 - 238.0 Vdc			
Reconnect voltage (signal)	115.0 - 135.0 Vdc				230.0 - 270.0 Vdc			
BATTERY								
Type	Deep cycle lead acid (LA)							
EFFICIENCY								
Charger peak efficiency	> 98%							

Figure 19. LEONICS SOLARCOM SPM CC Operating Specifications

This charge controller comes at an approximate cost of 700$ USD.

2.2.6 DC Combiner

Every PV system bigger than a single house-hold installation needs a DC combiner box. In common PV systems, in each string several modules are wired together in series. This results in cumulative voltage throughout the string, why the current remains constant. For the strings to meet and be combined in parallel, a DC combiner box is needed. It usually contains overcurrent protection devices and the necessary bus bars and terminals for the input combination.

A DC combiner box capable of handling the voltage produced by the arrays planned in the previous chapter is required. The combiner model **MidNite MNPV6-250** has been chosen to fulfil this task. It is designed to handle up to 250V to the charge controller and can hold up to 15 strings. Also, it is capable of withstanding 50kW of power. It comes at an approximate cost of 110€.

The following table provides the DC combiner's key features. Additionally, the following figure corresponds to the physical DC combiner device.

Feature	Value
Model	MidNite MNPV6-250
Max Voltage	250V
Number of Strings in BUS	15
Max Power	50kW
Cost	110€

Table 15. MidNite MNPV6-250 Features

Figure 20. MNPV6-250 Combiner Box

2.2.7 Battery Bank

One of the main goals when designing the site is for Mpaga to become energetically independent so the community's dependency on diesel supply decreases significantly. To achieve this, reducing as much as possible fuel consumption will a relevant factor in the dimensioning of the site. For this reason, a reliable battery bank will be an essential component.

Typically, most batteries used for solar installations were based on a lead acid technology. Lately, lithium ion batteries are becoming popular too. These are more efficient, weight efficient and can operate under more work cycles than lead acid batteries. Despite these advantages, their cost is still a difficult barrier, as lead acid batteries are a time-tested technology that can be purchased at a way lower price. For instance, Lead Acid batteries are widely commercialised at an approximate cost of 120$ /kWh battery, whereas lithium ion batteries will cost around 600$/kWh. (These prices depend on brand, model and system size). Additionally, lead batteries are more widespread and can be more easily found. The following table portrays performances indicators for both technologies in a 100kWh capacity storage installation. Lead Acid batteries are highly affected by operating temperature, so two columns corresponding to different temperatures are included.

	Lead Acid (25ºC)	Lead Acid (35ºC)	Lithium-ion
Battery Cost ($/kWh Storage)	120	120	600
Cycle Life (at 50% Discharge)	1000	500	2500
Transportation ($/kWh Storage)	28	28	5
Average Lifetime Cost ($/kWh throughput)	0,34	0,67	0,42

Table 16. Battery Technology Comparison

Despite the values shown in the previous table, some factors should be considered: The battery cost will depend on the chosen model (Voltage and AH capacity), transportation costs will depend on how easy to access the location is, and cycle life will again strongly depend on the brand and model. However, these values can be used as references or guidelines. In an extremely warm location, lead acid would probably not be recommended, as it significantly affects its life expectancy. Considering that Mpaga is a tropical region (low temperature variance during seasons) and that its yearly average temperature is 25.28ºC, this should not be a major issue. In conclusion, after analysing these indicators, it has been considered that although Li-ion batteries may have more optimal performance indicators from a technical perspective, its elevated cost makes Lead Acid batteries a better choice for the installation in Mpaga.

Lead acid batteries usually consist of several single cells, which produce approximately 2.1V, which are connected in series to reach de battery nominal voltage. A battery cell consists of two leaded plates: a positive plate that is covered with a lead dioxide paste, and a negative plate, made of sponge lead.

These plates are separated by an insulated material. These plates are typically enclosed in a battery case and then submersed in an electrolyte, which consists of distilled water and sulfuric acid. The size of the plates and the amount of electrolyte will affect the amount of charge lead acid batteries can store. This is usually described as the amp hour (AH) rating of the battery. Different values of current will result in different maximum charging times. Still, batteries do have an operational current range, which is determined by the manufacturer. The following figure provides a simple diagram of the already mentioned components in a lead acid cell and 12V battery formed of six cells connected in series.

This kind of batteries suffer a decrease of the expected number of cycles as the discharge depth increases. A maximum discharge of 50% will be fixed for the installation. The necessary maintenance of these batteries will be explained in Chapter 2.3.2.

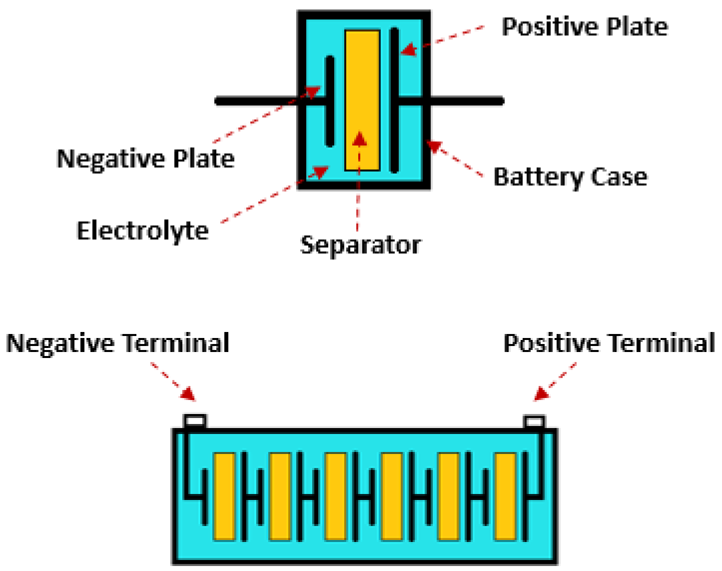

Figure 21. Lead Acid Cell and Battery Diagram

The next step in the design of Mpaga's battery bank is to choose a LA battery model and analyse its electrical and mechanical properties. Firstly, the nominal operating voltage of each battery must be defined. Given that batteries will be connected in series to achieve a voltage of 240V to match the charge controllers' and inverter' (all inverter considerations explained in following section) requirements, choosing a nominal voltage for each battery may be slightly less relevant than in other designing circumstances.

Deep cycle batteries’ most common voltages are 2V, 6V, 12V and, although slightly less, 48V. Despite this, these batteries are made up of usually 2V cells wired in series. For the site in Mpaga, it has been determined that the nominal voltage of the batteries in the battery bank will be of 12V.

The chosen battery mode is Rolls Surrete S-105. The model is a 85AH 12V flood lead acid battery that at 50% discharge cycles will be able of withstanding around 1200 cycles. Its terminals are Universal Type and it is formed of six 2V cells wired in series. The following graph shows an estimation of the number of cycles depending of the depth of discharge.

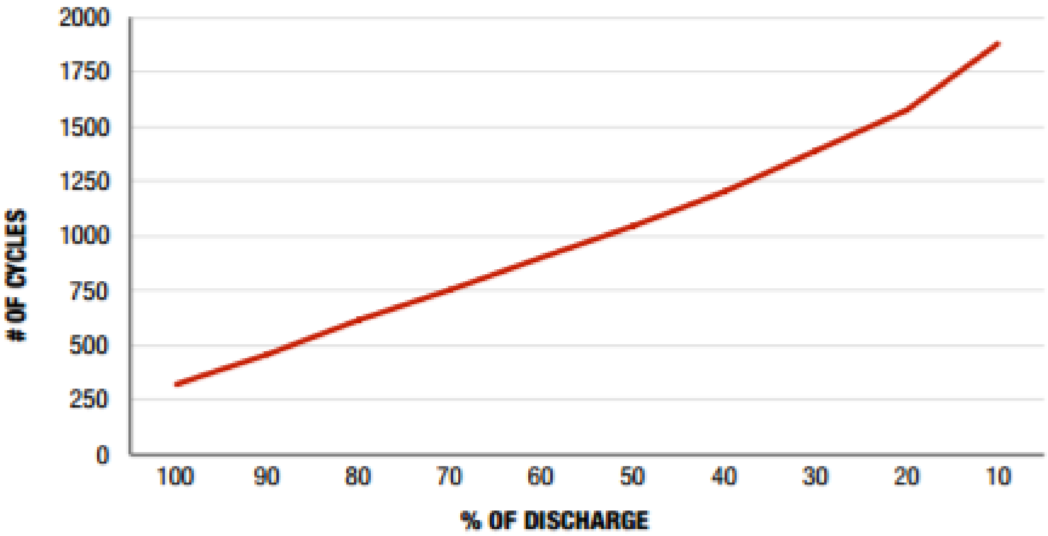

Figure 22. Rolls S-105 Number of Cycles Graph

The profile for this model has been created with PVSyst according to the manufacturer's specifications to obtain the following graph, which shows different discharge times for different discharge currents.

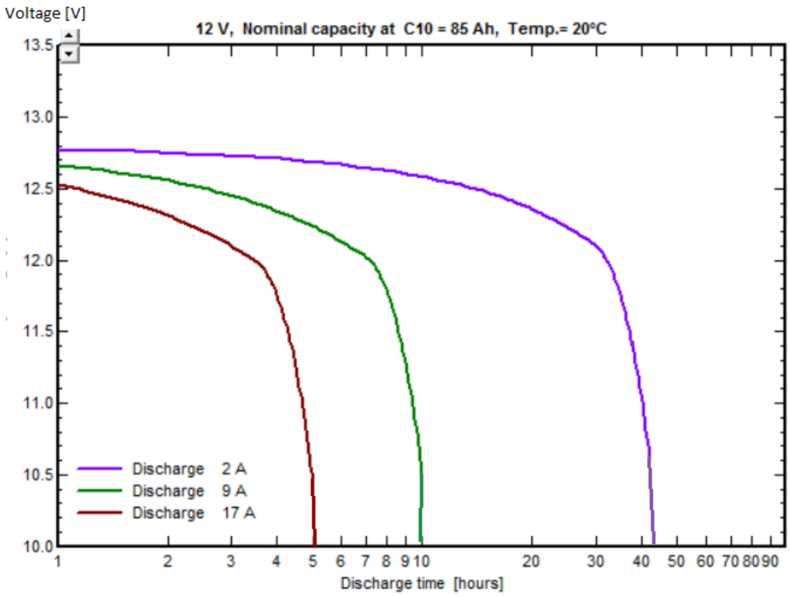

Figure 23. Discharge Times for Rolls S-105

These batteries, of a nominal capacity of 85AH at 12V, have a nominal energy capacity storage of 1,02kWh. Considering the size of the system and the commercialised prices for this model, the price for each kWh stored with the Rolls S105 model would be of 137,25 $.

2.2.8 Inverter

Solar inverters, or converters, are used in solar installations to convert the variable direct current output of the PV panels into AC current, that can be used by the local villagers in Mpaga. Some inverters have special functions that are adapted for use of PV systems, such as the MPPT charge controllers mentioned above. To size the inverter, several factors must be considered: The energy and power output of the solar array, the total PV panel installed, whether a central inverter or a multiple inverter system is desired, etc. The exact current the inverter will have to convert is a value that will only be known when the optimisation process concluded and the most optimal iteration is selected. However, this exact value is not needed to choose a suitable inverter.

After analysing several commercialised options that would fit in size with the installation's dimension and requirements, the **LEONICS Apollo MTP-410 series** has been chosen as the most suitable inverter for the Mpaga project. This would act as a unique central inverter and control unit for the entire site.

Some features of this model are as follows:

- Three phase bidirectional inverter with built-in output transformer, operating at 95% efficiency.

- Separate DC Bus for multiple source charging.

- It constantly minimizes the AC charging current from the generator, therefore lowering operation costs and emissions.

- Allows for the generator to be controlled automatically or manually.

- Automatic battery equalization.

- Battery temperature compensation.

-Optional parallel operation.

- ISO 9001 and 1400.

- 25+ years life cycle

The following table provides information on which model from the MTP 410 series is the most suitable for different power needs. Given the fact the maximum power demands are around 50kW, and considering efficiency factors, the installation will probably need the **MTP-417F Model.**

MTP-411E	MTP-412E	MTP-413E	MTP-411F	MTP-412F	MTP-413F	MTP-414F	MTP-415F	MTP-416F	MTP-417F	MTP-418F
10 kW	15 kW	25 kW	10 kW	15 kW	25 kW	30 kW	45 kW	60 kW	75 kW	90 kW

Table 17. MTP410 Series models according to Power output (kW)

Besides the proper inverter, the LEONICS Apollo MTP-417F has a battery equalizer, which manages and controls the charging of batteries. Battery equalizer is designed to reduce loses and increase the battery bank life by preventing imbalances and different states of charge in batteries in a same string. They are used to charge strings of batteries connected in series and charged as a single unit.

This device still operates under DC current, and is connected to the LEONICS APOLLO Control CPU. This device is in charge of minimizing the amount of power produced by the generator. Unless the solar panels or the battery bank cannot deliver the demanded supply, the generator will stay inactive.

The following figure corresponds to the physical appearance of the chosen product.

Figure 24. LEONICS Apollo MTP-417F

2.2.9 Wiring and Circuit Breakers

Most of the wiring in Mpaga is already installed, as there is now an operative energetic system supported by diesel generators. Therefore, there is no need to model or design the wiring from the generator or inverter to the loads. The rest of components should, however, be considered in the modelling to the wiring section. Cables will be needed from the PV panels to the DC combiners, and from the DC combiners to the Inverter going through the MMPT and charge controllers. To decide which type of wiring is needed, the current going through the cable is a necessary input.

A common method to dimension DC current wires is to use the following formula :

$$S = \frac{2 \cdot L \cdot I \cdot \rho}{V_A - V_B}$$

Where:

$S = Cable\ Section\ (mm^2)$ $I = Current\ (A)$

$L = Cable\ Length\ (m)$ $\rho = Resistivity\ (\Omega \cdot \frac{mm^2}{m})$

$V_A - V_B = Tension\ Fall\ (V)$

Three distinct types of cable will be needed. Firstly, the wires that will be used to connect every panel in one string. Secondly the wires used to deliver the power from the charge controller to the main DC Bus. Once all the cables from the charge controllers meet, a larger cable will be needed in order to deliver the power to the battery bank and the inverter. The following provides the variable values for each type of cable, as well as the section obtained by applying the previous formula.

	Voltage (V)	Current (A)	Length (m)	Resistivity	Max Tension Fall Rate	Section (mm^2)
String Cabling	200	10	10	0,0176	1%	1,584
DC Combiner to DC BUS	240	55	30	0,0176	1%	24,2
DC BUS Wire	240	800	4	0,0176	1%	46,933

Table 18. Cable Section Calculation Parameters

As it can be observed from the table, the last type of cabling should withstand a current value much higher than the other sections, as in this section all the power from the solar PV panels merges. To lower costs, this section has been designed to be as short as possible. By making the cables coming from each solar array / charge controller longer than necessary, it is possible to design a shorter DC Bus Cable. Following the formula above, the lower the cable length, the lower the section must be, the lower the cost for the wiring. It must be noted, however, that these values are approximations.

For the first cabling section, where a wire section of at least 1,58mm^2 is needed, a H07RNF 2.5 mm^2 section would be a safe model to choose. For the second section, where at least 24,2 mm^2 are needed, 35 mm^2 H07 RNF model would also be a suitable model. Lastly, for the DC BUS wire, where all the solar arrays meet, model 50 mm^2 H07 BN4F would be a safe value to use. However, a H07 BN4F 70 mm^2 model has been chosen, in order to have a wider margin of error for the most critical section. Full product brochure is available in the annex.

2.2.10 Mounting Racks

Although these components may seem less relevant in the electric functionality of the site, they still need to be considered, as they are necessary to operate the solar panels. Some companies offer pre-sized sets for a certain installed power. Company Sunforson provides Sets sized for 10kW of installed PV panels at a cost of **600$ USD /set**, approximately. These racks have the following specifications:

Model Number	Installation Angle	Wind Load	Price	Module Orientation	Support Rail
SFS-GM-04	0º-60º	42 m/s	600$/set	Vertical	Extruded Aluminium

Table 19. SFS 10kW Rack Set

Additionally, the following table provides all the components present in one of the mentioned Rack sets.

SFS-SR2-3100	SFS SunRack Rail II (3100mm) Extruded Al6005-T5 Anodize	SFS-EG1-50	SFS End Clamp Group(50mm) Extruded Al6005-T5 Anodize
SFS-MG1-50	SFS Mid-Clamp Group(50mm) Extruded Al6005-T5 Anodize	SFS-SC-02	SFS Splice Connector Extruded Al6005-T5 Anodize
SFS-FG-04	SFS L-Feet group Extruded Al6005-T5 Anodize	SFS-SM1-30	SFS Support Mounts Group Extruded Al6005-T5 Anodize
SFS-ES-10	SFS Expansion Screws 304 M10*100	SFS-SM2-30	SFS Support Mounts Group Extruded Al6005-T5 Anodize

Figure 25. Components Present in SFS Rack Set

2.2.11 Designed System with Chosen Components

The following diagrams picture Mpaga's microgrid with the chosen commercial components. This first diagram's aim is to portray a physical representation of the chosen components' appearance and their layout in the installation.

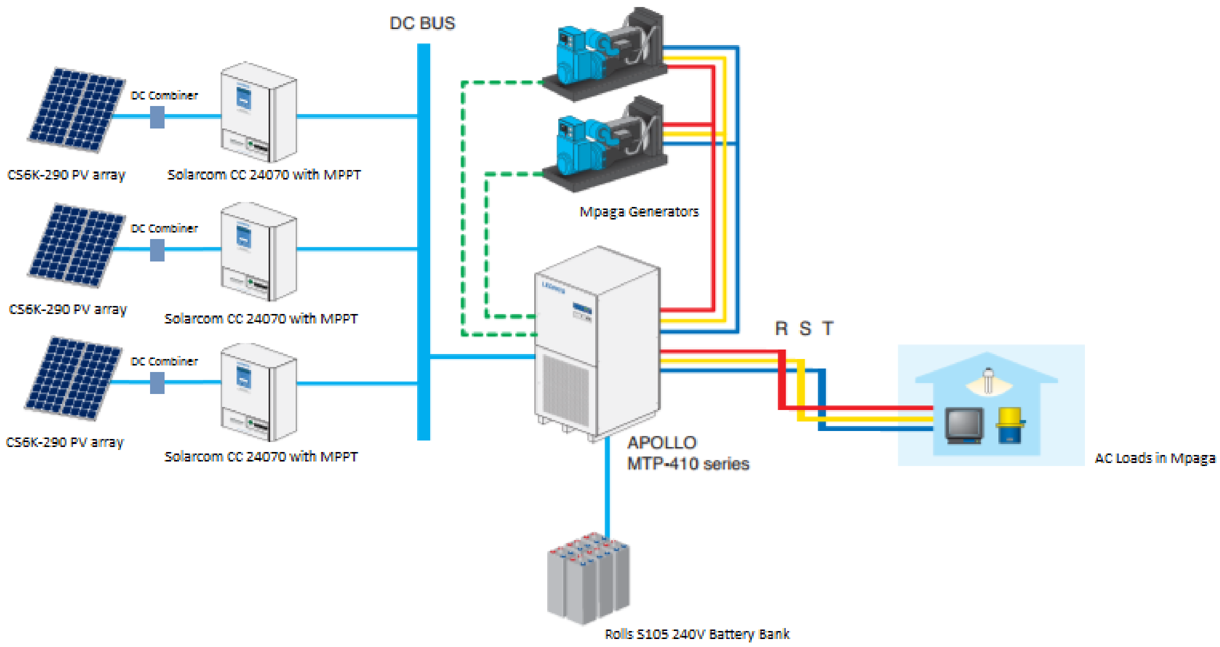

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Figure 26. Mpaga Microgrid Commercial Component Layout

On the other hand, this second diagram shows the circuits main components. Some commercial devices include several components. These have been indicated with a dotted line, naming the commercial device as well as its different functionalities.

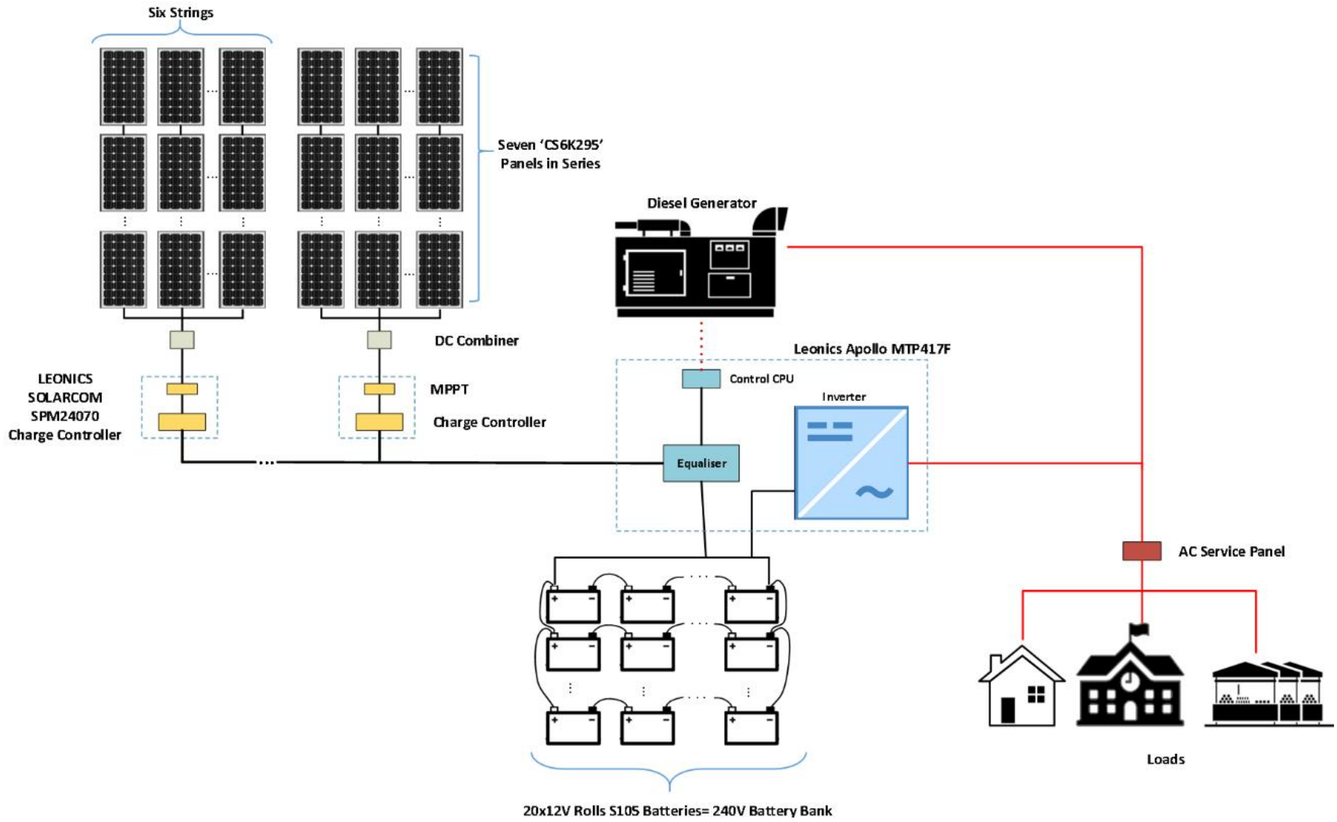


Figure 27. Mpaga Microgrid System

2.3 Rural Electrification Considerations

Before starting the design of Mpaga's microgrid, several similar cases have been studied, and these have allowed us to take into consideration some factors that were probably not obvious. The IRENA institute provides more information on these cases and considerations.

2.3.1 Business Model

To begin evaluating the main factors that affect our design, it is essential to have a clear idea on the business model upon which the Microgrid will be based. Microgrids can usually be divided into three diverse kinds of business models, depending on the way they are funded or paid for. Firstly, some projects may be carried out for profit reasons, where economic viability and financial success are the main goal. A thorough tariff design and tariff collection is vital for these projects to succeed. Secondly, some projects are partially subsidized, meaning that while they still collect tariffs for energy usage, their main capital costs are paid by large subsidies. In this type of model, tariff collection is mainly used to cover operation and maintenance expenses. Lastly stand fully subsidized models, which is probably the model that would best suit Mpaga's community situation. In this case, the costs are not fully subsidized by the local government but by ESPACE AFRIQUE foundation. These type of business models often collect below cost-recovery tariffs to cover O&M and administration expenses. In the following chapters, several features of the installations design that are essential for the project to succeed will be studied, bearing in mind that it's a fully subsidized project.

2.3.2 Key Factors

When it comes to the design of any kind of Rural Microgrid, it has been proven that the project cannot only focus on purely technical premises, but instead, adapt to specific social and economic characteristics of the rural community. We find seven critical factors that must be thoroughly planned, which are as follows:

- Tariff design
- Tariff collection mechanisms
- Maintenance & contractor performance
- Theft management
- Demand growth
- Load limit
- Local Training and Institutionalisation

In this chapter, the identified factors above will be analysed in detail according to Mpaga's specific situation

2.3.2.1 Tariff Design

Being a fully subsidized project, this may seem a barely relevant factor for our project. However, after studying several real cases of design and installation of rural microgrids, we come to a clear conclusion: All projects where energy was given at zero cost, community members soon started giving it for granted and partially, if not fully, ceased to perform their duties. It has also been proved that projects where an external institution takes care of all capital and maintenance costs have really high chances of failure once the institution departs the site if community members do not feel involved in the project and its maintenance tasks. Therefore, an affordable-for-everyone tariff that at the same time makes every community member feel involved in the project seems necessary.

However, Mpaga has a complex and unique social distribution. On one hand, as mentioned in previous chapters, the village's main activity is the boarding primary and secondary school. ESPACE AFRIQUE FONDATION takes care of all the school's costs. In other words, being the foundation the funder of both the school and the microgrid installation, it would seem too productive to design a tariff thought for the school institution. Nonetheless, the rest of the community members, which are not enrolled in education tasks, could contribute with some kind of asset in exchange for the energy service provided. The most obvious solution would be to make estimations or calculations of what will be each villager's or group of villagers' consumptions, and decide a fair tariff (although far below market price) for these to pay. However, some villagers may be totally unable to provide any economic aid, regardless the amount. In these cases, given the microgrid is thought to provide energy for the whole community, other agreements could be arranged. For example, engaging in community services as a method of payment, or committing to help in the maintenance tasks that don't require technical expertise. Some of these alternatives will be discussed in further chapters.

2.3.2.2 Theft Management

When rural electrification is implemented following profitable business models, theft managements is usually a very important issue to handle and plan thoroughly. However, in this type of business model, which is totally subsidized and meant for all community members, this will probably not be a relevant problem. However, inappropriate use of the installation, such as over-consumption, could indeed put at risk the performance of the microgrid, creating partial or total energy shortage. This matter will be analysed in the following chapters, and the most suitable over-usage prevention methods for Mpaga will be studied.

2.3.2.3 Demand Growth

In order to design a suitable installation, it is not only necessary to consider the actual power and energy demands, but to also bear in mind that it is very possible the community may continue to grow. Therefore, a growth prediction must be considered when dimensioning the installation. Occasional over usage of the predicted consumption per load may be normal. However, under dimensioning the installation or failing to consider its probable growth could result in a constant energy shortage.

Gabon's main economic activity during the past decades has been crude oil extraction, and to a lesser extent, its refinement. It is Africa's 5th largest producer of oil. This has typically represented a GDP annual growth of approximately a 4%. However, the price of oil has suffered severe decreases over the past three years, and this has represented a significant back down for the country's economy, meaning it's growth has decreased to a 1% -1.5%. This information is considered as something to bear in mind as a national general trend. Mpaga Community has a very specific framework and should also be considered individually.

Having a constant, reliable, and very cheap source of energy available will definitely be an attractive asset for members of close-by communities or villages. For this reason, a successful installation of the microgrid could end in a significant increase of Mpaga's population and social and professional activity. While this would be positive for the community's economy and independency, it would mean that the initial necessary energy production could soon become outdated.

For example, the water pump 's consumption has been considered, although it represents a relevant value compared to the total power. Additionally, a 15% variation has also been considered. If this happened to fall short, the installation has been designed so that additional PVs can always be added in the form of new solar arrays without this having a critical impact on the global cost.. Under sizing the installation or failing to consider demand growth could have worse consequences if we were dealing with generators, as it would be far more difficult to increase the installation's capacity.

2.3.2.4 Load Limit

It has already been mentioned that the most dangerous issue in this project will not be power theft, but possible over-usage of the calculated consumptions. For example, if one of the bar or markets considerably surpassed its allowed consumption, this could mean the installation is unable to support the power needed by the school's lighting or food conservation. Therefore, in order to prevent over-usage, load limitation must be considered. Several actions can be performed in order to lower the risk of energy shortage. These are as follows:

- Customer Agreement: This is the easiest prevention method to carry out, and should ideally be enough to preserve the installation in a constant performance. It basically consists in reaching an agreement with each consumer or load point as to their maximum power and energy consumption. Given the lack of technical understanding of the villagers, this information should be given not in typical energy or power units, but in appliances equivalencies. This method, although necessary, is likely to not be sufficient to prevent users consuming more energy than allowed. This must be a written and official agreement. For these reasons, other prevention methods will also be necessary.

- Load Limits:

If the written agreement fails, other methods must ensure the installation is not put at risk. Individual mini circuit breakers or fuses in each point of consumption could be used to ensure that users do not exceed their maximum power consumption. Also, load points should be equipped with a counter, so users can easily keep track of their consumption.

-Penalties:

If customers fail to achieve what is stated in the agreement, penalties should be applied to discourage consumers of over-consuming. Temporary disconnection for users who overstep their agreements are a simple solution. They may seem harsh, but it has been proven in other study cases that zero tolerance is necessary in these situations.

-Limiting Business Hours:

To avoid extremely high peak power hours, business hour limitation is a very useful prevention method. Mpaga's most energy demanding hours will be during night-fall, as lighting will be most needed, and during business hours. Establishing limits to markets, shops, bars or any other consumption point as to at what hours their business can consume electricity is a straightforward way to avoid critical peak-times. In further chapters, where detailed consumption approximations are performed, we will see how this method has been applied.

2.3.2.5 Local Training and Institutionalisation

The first step for starting the real implementation of the microgrid once the design is completed is the creation of a local institution within the community. This institution will oversee the installation's management, maintenance schedule, tariff collection, theft management and load limitation. Members of the community can perform minor maintenance tasks, but these must be organised and monitored by an official local institution.

Given the lack of technical expertise within Mpaga community, a long preparation period of the local institution will be necessary. This will include basic technical training for O&M, as well as capacity building and reaching load consumption agreements with community members. ESPACE AFRIQUE Foundation was on the verge on employing an electrical engineer to perform maintenance tasks on the diesel generators. He would be in charge of providing local villagers basic technical training so they can help with simple O&M tasks as a form of tariff payment. Other more complex tasks would be performed by this engineer.

Making sure the installation does not put risk the health and well-being of any community member is essential. This may be a challenge, considering the total lack of electrical knowledge within villagers. For these reasons, implementation of comprehensive safety measures, such as illustrated posters or brochures, must be performed with enough time before the installation starts operating.

Although all the community members have been considered in the design planning, some aspects of Mpaga's daily routine may difficult to predict by a third's party study. Therefore, it would be highly recommended to make sure all the stakeholders feel involved in every step of the process by holding constant consultations during the preparation process.

2.3.2.6 Maintenance

Local Institution will be in charge of performing basic maintenance tasks in the solar microgrid. Besides assigning the tasks to the community members, a thorough maintenance task will be kept in schedule maintenance sheets. The most typical O&M tasks in a solar off grid installation are:

-PV Modules: PV modules are the component which needs maintenance more frequently. However, it usually does not require any technical expertise as it basically consists in cleaning the modules. When PVs are located in building roofs, extra safety measures are needed to perform these tasks, but in Mpaga the PVs will be placed on level ground, in a spacious sandy area close to the primary school. During rainy season, these tasks may not be necessary.

- Batteries:

Generally, maintenance of batteries will concentrate on correct charging regimes, electrolyte condition, battery terminals and overall battery safety. The basic safety equipment consists of a hydrometer for checking specific gravity of the battery's electrolytes, a glass bulb type thermometer, a container filled with distilled water to rinse the hydrometer, handheld multi-meter, plastic type dishwashing cleanser to clean the battery terminals, and baking soda for the cleaning of batterie

A basic maintenance will require regular battery checking, which should include a revision of its cleanliness, electrolyte levels, terminal condition, container's condition and battery voltage level. These tasks require a certain degree of technical expertise, and will be probably only performed by the maintenance engineer.

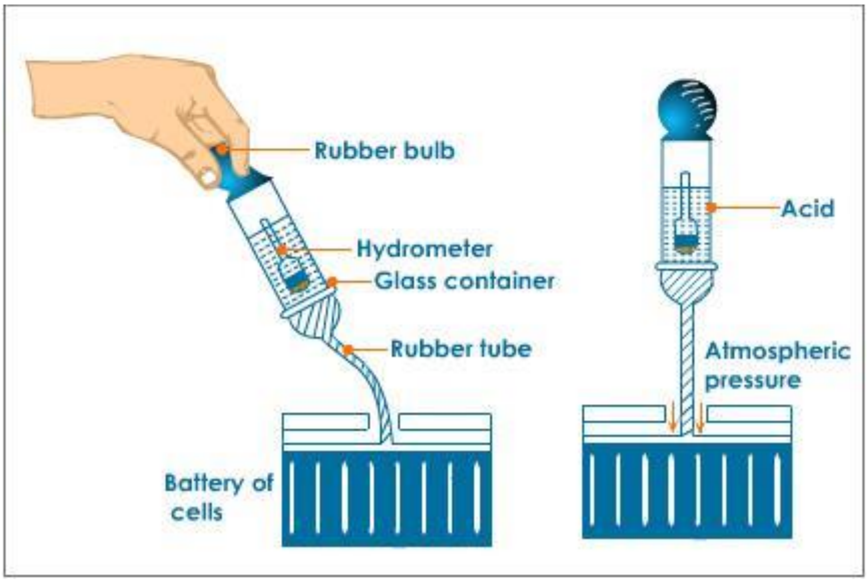


Figure 28. Hydrometer Usage

Batteries performing under high temperatures will represent in a more frequent need of water addition. Only distilled water should be used, never tap water, as its minerals would reduce the battery's capacity. Battery electrolyte levels should be just below the bottom of the ventilation well, and about half an inch above the tops of the separators. The electrolyte levels should never be allowed to drop below the top of the plates.

- Inverters:

Maintenance of inverters is not usually an issue. Tasks to prevent risks include operation mode checks, such as checking the inverter starts operating almost immediately after an appliance is turned on. The inverters will also need cleaning after a certain period. This task should only be performed with a dry cloth or brush. It is also common for spider-webs to appear in the ventilation grills, or for wasp nests to appear in heat sinks, especially in tropical zones such as Mpaga. With the aid of the technical engineer, local villagers should be well prepared to undertake these kinds of tasks.

- Switchboards and Wiring:

Besides visually checking for corrosion or burning, this equipment should not require a scheduled maintenance plan. However, considering Mpaga has a heavy rainy season during some months of the year, it will be necessary to make sure everything is properly sealed, but these are typical procedures in every installation.

2.3.2.7 Collection Mechanisms

Once the tariff has been designed according to the previously mentioned criteria, the mechanisms used to collect these payments must be carefully thought and planned. In Mpaga, this may also not seem one of the most crucial factors at first sight, as one could think that given that most consumers will not pay an economic tariff, this section is rather pointless. However, ensuring the compromises consumers agreed to in order to be able to consume from the installation, whatever these may be, can be a complex task. Ideally, villagers should deliver and perform, for instance, the cleaning maintenance duties they agreed to do without major trouble, but it frequently does not work this way. Reaching an agreement with the police officers in Mpaga to help the institution make unwilling villagers cooperate will be the most important task when planning collection mechanisms.

2.3.3 Virtuous & Vicious Cycle

Depending on if the previously mentioned factors are considered or not, the installation may enter two very different cycles. IRENA Institute provides the following diagrams portraying a favourable or virtuous cycle, as well as the negative or vicious cycle. These diagrams apply for all microgrid installations. Although some of the factors it considers are irrelevant for Mpaga's situation, such as theft or cost recovery, it is a visual and clear way to understand how the previously explained key factors may interact between them.

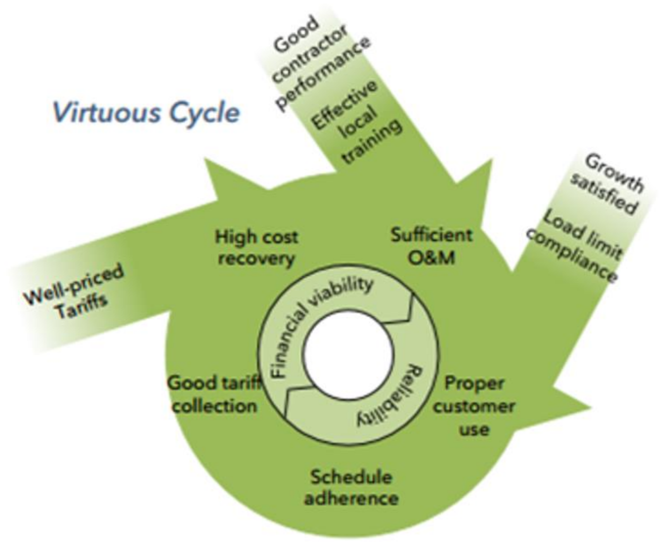


Figure 29. IRENA's Virtuous Cycle

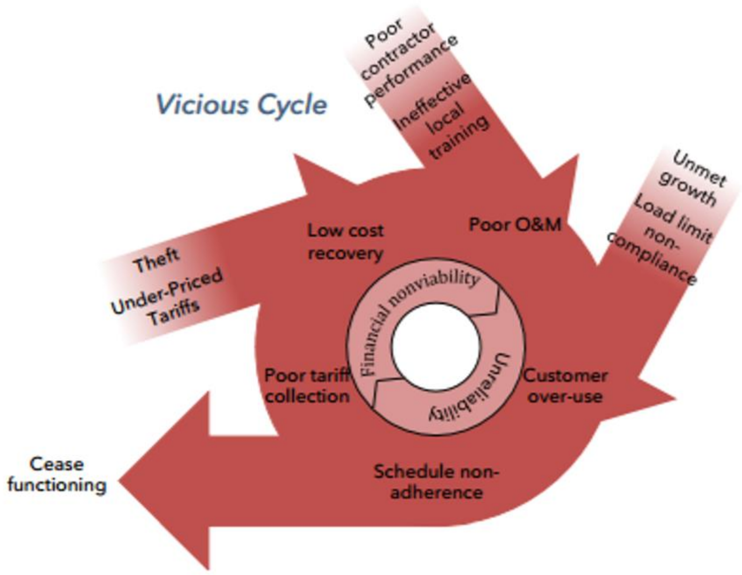


Figure 30. IRENA's Vicious Cycle

2.4 Iterative Optimisation and Analysis

Once every component has been chosen, and each input parameter has been defined according to the exact circumstances of the installation in Mpaga, an iterative optimising process is undergone to be able to determine the exact combination and distribution of power generation and storage that minimises capital and operating costs.

It is expected to obtain a model whose solar installed power is by far larger than its peak power demand. Typically, in significantly renewable installations this can be from four to six times the peak consumption. Diesel Generator should operate during a few hours during night hours, to help reduce the total initial cost in battery banks. Batteries charge periods will be during peak radiation hours, and will discharge during midnight, reaching their lowest charge level at dawn. As mentioned before, these batteries will never be discharged more than a 50% of their nominal capacity, to allow them to extend their life expectancy to around 1300 cycles. In the following two chapters, the optimiser's inputs will be explained or mentioned, and the best scenario results will be analysed.

2.4.1 Input Parameters

HOMER Energy Systems optimiser is used for this purpose. All the parametrisation values the optimiser needs have been calculated and explained above. However, these will be briefly stated once more as a reminder before analysing the most optimal solutions.

- **Diesel Generator**

Parameter	Value
Capacity	100kW
Electrical BUS	AC
Initial Capital	0 $
Replacement	20.000 $
O&M (per hour)	0,6$ / hour
Minimum Load Ratio (%)	10%
Lifetime (Hours)	25.000 hours
Diesel Fuel Price	1,15 $/litre

Table 20. Diesel Gen Homer Inputs

- **Load**

Parameter	Value
Day-to-day variation	15%
Load Type	AC
Load Profile	(see 2.2.2)

Table 21. Load Homer Inputs

- **Leon 25 Inverter**

Parameter	Value
Model Name	LEONICS MTP417
Price	45.000$
Price per kW	600$/ kW
Inverter Lifetime	25 years
Inverter Efficiency	96%
Rectifier Relative Capacity	80%
Rectifier Efficiency	94%
Parallel with AC generator	Yes

Table 22. Leon Inverter Homer Inputs

- **CS6K-295 Solar Panel**

Parameter	Value
Model Name	CS6K 290MS
Rated Capacity	0,290 kW
Temperature Coefficient	-0,39
Operating Temperature	45 ºC
Efficiency	17,72%
Price	680$ / kW
Lifetime	25 years
MMPT Tracker	Yes
Derating Factor	88%
Ground Reflectance	20 %
Electrical BUS	DC

Table 23. CS Solar Panel Homer Input

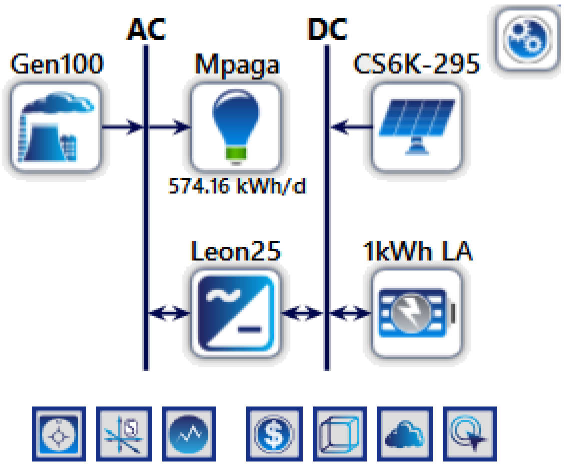
- **Rolls 24-M Lead Acid Battery**

Parameter	Value
Model Name	Rolls S105
Nominal Voltage	12 V
Nominal Capacity	1,02 kWh
Nominal Capacity	85 Ah
Capacity Ratio	0,403
Maximum Charge Current	16,7 A
Maximum Discharge Curr	24,3 A
Price	140 $ USD
Lifetime	10 years
String Size	20
Voltage	240V
Initial State of Charge	100%
Minimum State of Charge	50%

Table 24. Rolls 24-M Battery Homer Inputs

2.4.2 Optimisation Results

After analysing every combination proposed by the optimiser considering the previous inputs and restrictions, the following result table is obtained. The results will be firstly exposed as in the result table from the optimiser, and afterwards converted to values such as number of components or total cost for each component. The following figure shows the installation's schematic, with the components that require the main input parameters.



Installed PV (kW)	Battery Storage (kWh)	Inverter Capacity (kW)	Renewable Fraction (%)
299	840	63,1	92

These are some of the main results provided by the optimiser. Although they can be used as a guide, a deeper insight is needed in order to obtain useful conclusion regarding the dimensioning of the whole installation. Each of the main components result will be now analysed, to provide an understandable outcome of the obtained results.

2.4.2.1 Diesel Generator

The renewable distribution of the proposed site would be of a 92%, compared to the actual 0% operating in Mpaga. For this reason, it is obvious that the new installation's fuel consumption will be much lower. The daily consumption of the site would be of 18,5 litres on average, which is a considerable decrease compared to the actual 189 litres per day. The diesel generator will be working for 1059 hours per year, which is the equivalent to 2h 54 mins daily.

When analysed from a financial point of view the improvement is, logically, considerable. The diesel generator's fuel supply represents an annual cost of 78.000$ annually. With the site dimensioned in the proposed conditions, this would be reduced to 8.943 $USD. The following table compares the fuel consumption of the actual installation with the one being designed.

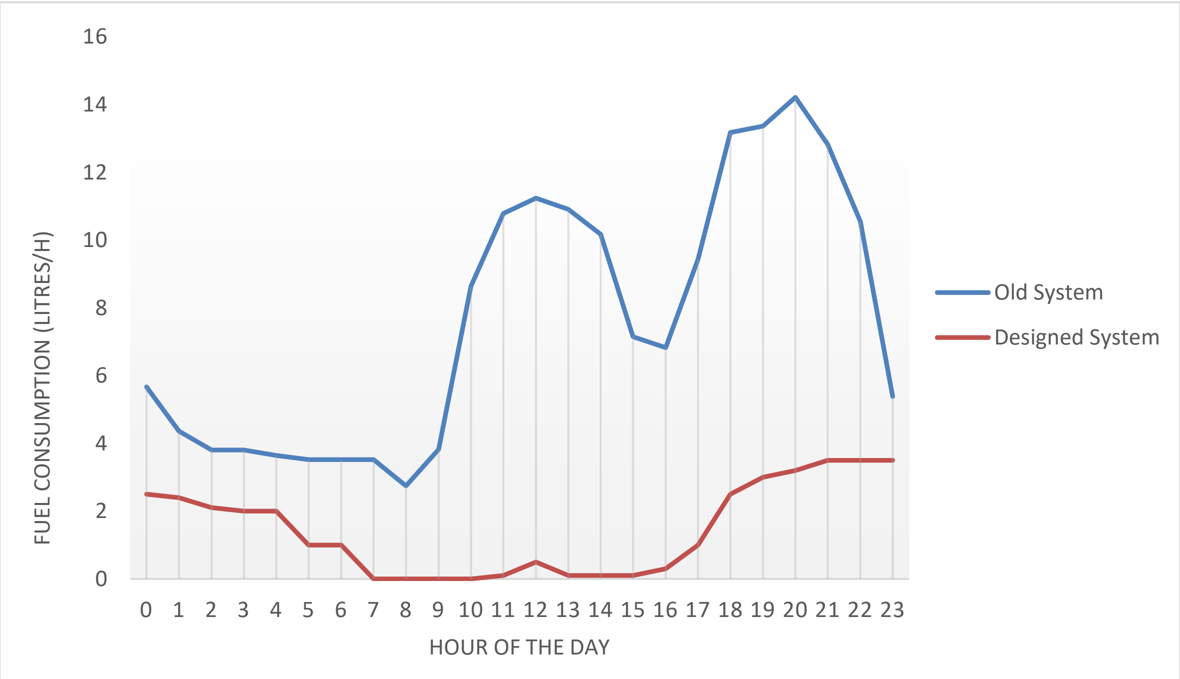


Figure 31. Fuel Consumption Comparison Between Old and Proposed Systems

The following table provides the necessary information to understand the generators operation in the proposed installation. The values on the table correspond to the annual average, and may suffer minor variations from day-to-day.

Fuel Consumption (l)	Operating Hours	Fuel Annual Cost	Energy production
18,5 litres/day	2hours 54 mins /day	8.000 €	52.1 kWh/day

Table 25. Diesel Generator Operating Values

2.4.2.2 Solar Panels

Solar Panels will be the primary source of energy production for the installation in Mpaga. They must provide enough energy supply to overcome the load demand during most of the time and to charge the batteries during high irradiance hours. Therefore, the total amount of installed solar panels will be considerably higher than the peak power demand.

The total amount of installed power that would be needed in order to operate the site in a clearly renewable and non-diesel dependant mode, and that ensures this is done at a minor cost is *299kW*. In other words, *1032* Canadian Solar CS6K-290 Solar Panels should be installed to cover the demanded energy supply. Each solar panel comes at 198$, so this would represent a total solar panel initial cost of *204. 366$ USD.*

As mentioned before, it is easy to point out that this is much more than the peak power demand. However, our selected panels only supply their nominal power value (290W) on optimal condition. This is, the hours in the day which receive most solar irradiance, in the days of the year that too receive most irradiance. The site must be able to operate without major issues during all days in a year. While it is true that if a given day had an extremely and unusual low value of solar irradiance, the diesel generator could keep the system working by increasing its energy supply. This could be a sensible solution for specific and very rare days, but could compromise the financial viability of the project if they became a frequent situation. For these reasons, the value of 299 kW of installed power seem a sensible value. The following table provides the annual average main operating values for the solar panels.

Installed Power	Number of Panels	Daily Production	Capital Cost
299 kW	1032	1078 kWh	203.428 $ USD

Table 26. Average Solar Panel Operating Values

As mentioned in previous sections, each solar array will consist of six panel strings, each string being composed of seven panels wired in series. Also, each of these arrays will go through a DC combiner Box to then be monitored by the MPPTs. Therefore, a DC Combiner and MPPT will be needed for every 42 panels. This means that 25 MPPT trackers and DC Combiner boxes will be needed. This information will be considered in the economic study of the installation.

The following tables show the irradiance received by the solar panels and the total power output of the PV installation on an hourly basis. The values shown in both graphs correspond to annual average values. Lastly, a graph portraying the operating temperature evolution of the cells is shown.

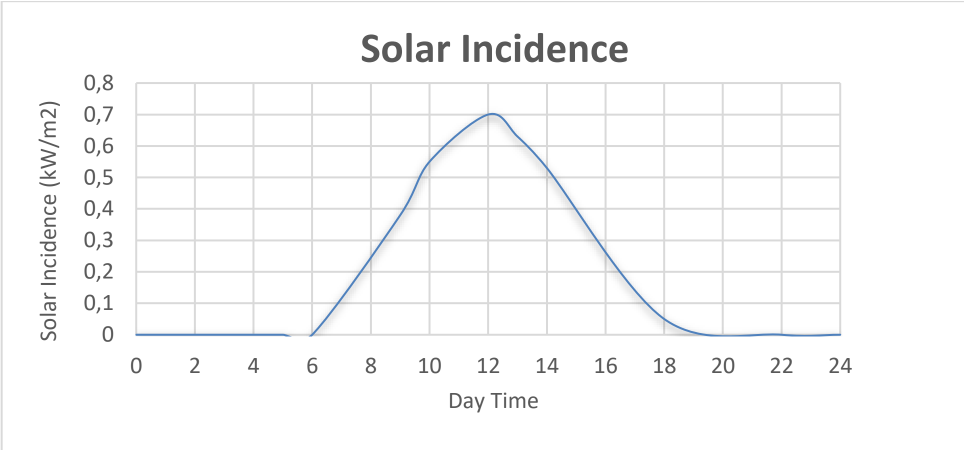


Table 27. Solar Irradiance Incidence.

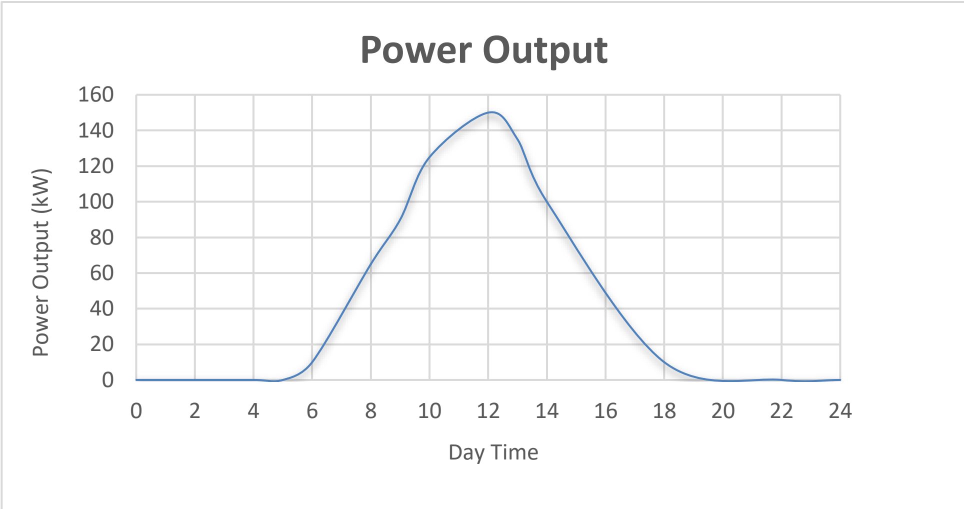


Table 28. Power Output Produced by the PV installation.

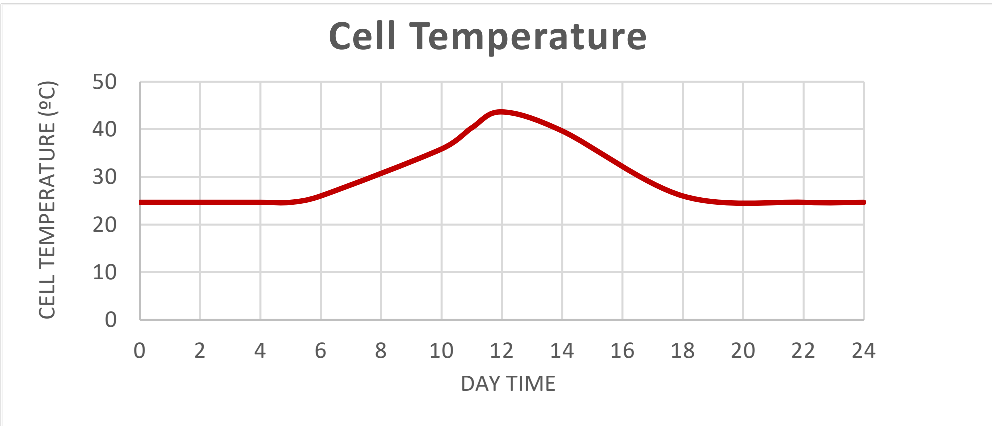


Table 29. Cell Temperature daily evolution.

The first graph shows the hourly evolution of the solar incidence per metre squared in an average day. If we measure solar irradiance in peak hours (1 kW/m^2) , Mpaga is receiving 4.74 peak sun hours per day. Next graph, showing the power output, provides a clear view regarding the importance of oversizing the installed capacity of the site. Although having an installed capacity of 299kW, it can be observed that the most productive hours are delivering around 150kW. This is due to efficiency factors in solar panels, batteries, wiring, inverter, MMPTs and solar charge controllers.

Lastly, the cell temperature evolution is considered due to the already mentioned fact that operating under higher temperatures than the nominal cell temperature has negative effects on the panel's efficiency. The cells nominal operating temperature is 45ºC. From the graph it can be observed that on an average day, cells do not operate, at any hour of the day, at more than 45 ºC. Must be noted that being a tropical region, temperature variation is almost neglectable from an annual point of view. For this reason, it does seem sensible to consider a graph showing an annual average, where as in other regions of the planet this would mean a much wider error.

2.4.2.3 Battery Bank

Battery Storage	Number of Batteries	Initial Capital	Autonomy	Daily Storage
840 kWh	824	115.294,12$	18h	308,48 kWh

The total number of batteries needed in the battery bank to ensure an acceptable performance of the site according to the previous input parameters is 824. To achieve the value of 240 V for the battery bank, 20 12V batteries will be wired in series. This means the battery would have 42 rows of several batteries wired in series. The exact number of batteries needed is not a multiple of 20 ,so to ensure that every battery string's voltage is 240V, 840 batteries would be needed. This will also provide a safer margin in case a slightly increase in storage was needed.

3 MICROGRID ECONOMIC STUDY

3.1 Cost Breakdown Overview

The following chart shows the several types of costs that should be considered when studying the project from an economic point of view. The cost of most of the hardware components has already been discussed, as it represents a relevant factor when it comes to choosing commercial components. Other direct costs will be treated in two subgroups. Firstly, electrical labour and construction will be dealt with in the Installation section, whereas Transportation will be treated separately in its own section. As regards Developer Costs, only a contingency percentage will be determined, as this thesis basically handles the engineering design and the administration will depend on ESPACE AFRIQUE FONDATION's criteria.

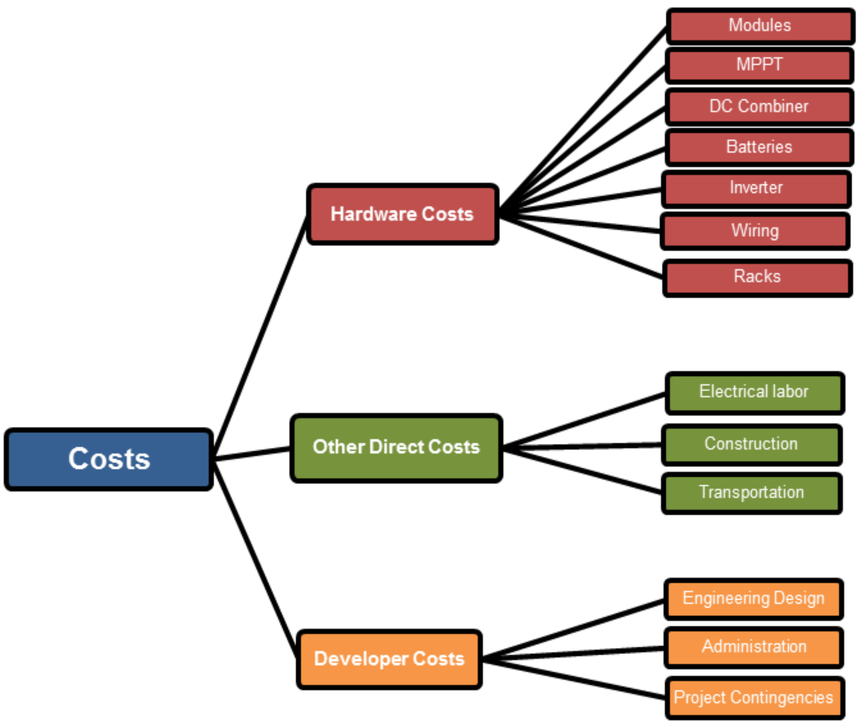


Figure 32. Cost Breakdown of Mpaga Microgrid

Additionally, in order to have a reference of what total initial costs can be expected, the following graph is provided. It shows the cost as in $ USD / Installed W depending on its total size for several projects, both on and off-grid, developed in Africa between 2011 and 2015. Given the size of the installed project is around 300kW, values in the range between 2$/W and 4$/W could be expected.

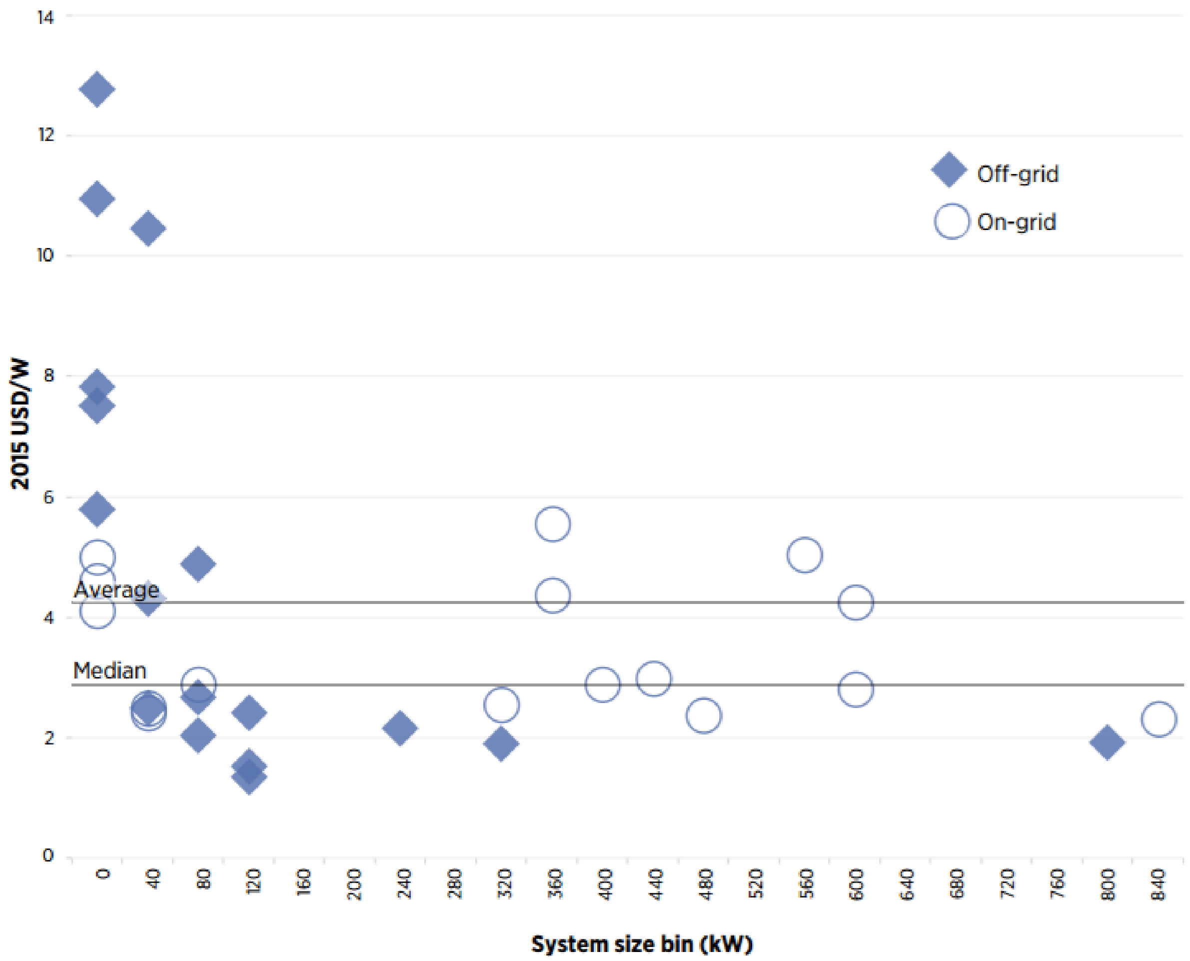


Figure 33. Minigrid costs by System size (Africa 2011-2015)

3.2 Hardware Costs

3.2.1 PV Modules

The costs from the PV modules has already been discussed in previous chapters, and will be briefly reminded. In order to install 299 kW with the model CS6K-290 , 1032 panels are needed. This has a cost of **203.320 $.**

No Maintenance costs have been planned for the panels. Usual maintenance cost for PV panels consists in cleaning, which will be done by community members as a form of tariff collection. Other more complex occasional maintenance can be done by the electrical engineer in Mpaga.

3.2.2 Mpaga Generators

The generators do not affect the initial capital investment, as are already present in Mpaga. However, it is recommended to change the oil every 100 hours of operation. A recommended diesel generator lubricant, *Shell Rotella T 15W-40 Heavy Duty,* comes at 30 $ USD per gallon (3.785 litres). The operational diesel generator in Mpaga has an oil capacity of 2 gallons. Considering this, we obtain the following yearly oil cost:

$$1233\ \frac{operating\ hours}{year} \cdot \frac{1\ oil\ change}{100\ hours} \cdot \frac{2\ gallons}{oil\ change} \cdot \frac{30\$}{gallon} = \mathbf{739.8}\frac{\$}{\mathbf{year}}\ \mathbf{in\ oil}$$

This is 0,6$/operating hour of O&M.

Other maintenance tasks will be done by the engineer in Mpaga, and will mean no cost.

Also, as stated before, fuel consumption will represent a cost of **8943 $USD / year.**

3.2.3 Battery Bank

The necessary size of the designed battery bank is of 824 batteries, and this coming at an initial capital cost of **115.294,12 $.** These batteries will have a total throughput of 1200kWh / battery. We now obtain the following calculation:

$$840\ batteries \cdot 1250 \frac{kWh\ throughput}{battery} \cdot \frac{1\ day}{308{,}48\ kWh\ consumption} \cdot \frac{1\ year}{365\ days} = 9{,}32\ years$$

This means the battery banks should be replaced around every 9 years. If a strong payment every 9 years is considered significantly inconvenient, the replacement could be done gradually. It should also be considered that replacing the batteries every 9 years also means transporting them to Mpaga. It is now considered that all the hardware equipment will be shipped from Europe. However, given how fast the renewable sector is growing around the world, but specially in Africa, it is difficult to determine if in 10 years or more it is still necessary to import all the technical material from Europe, or if it will be widely commercialised throughout Africa or Gabon. For this reason, when analysing battery replacement costs, no transportation fee will be considered.

3.2.4 DC Combiners and Charge Controllers

Each solar array consists of six strings of seven solar panels wired in series, a DC Combiner and a Charge Controller. This means, a DC combiner and a Charge Controller for every 42 solar panels. In order to install 1032 solar panels, 25 solar arrays will be needed. As a preventive measure, and given that the failure of one of these components would compromise 42 solar panels, 30 Charge controllers and 40 DC Combiner boxes will be bought. These devices usually have similar devices as the PV panels (25 years or more), and since the project's lifetime has been fixed in 25 years, no replacement costs shall be considered. As regards the initial capital cost for DC Combiners and CC:

$$30\ solar\ arrays \cdot 1 \frac{CC}{Solar\ Array} \cdot 700\$ \frac{USD}{CC} = \mathbf{21.00\$\ USD\ in\ Charge\ Controllers}$$

$$40\ solar\ arrays \cdot 1 \frac{DC\ combiner}{Solar\ Array} \cdot 110\$ \frac{USD}{CC} = \mathbf{4.400\ \$\ USD\ in\ DC\ Combiners}$$

3.2.5 Inverter

Although the LEONICS APOLLO MTP417F's cost is not of public domain, the optimiser's database does include the MTP400 series' price per kW. According to this database, this series comes at 600$/kW. The model chosen, MTP417F has a max. nominal output power of 75kW. This would represent an **initial capital cost of 45.000$ USD**

3.2.6 Mounting Racks

To mount the almost 300kW of installed solar panels, 30 *SFS-GM04* (can mount approximately 10kW of solar panels) mounting rack sets will be needed. This will represent an initial capital cost of **18.000$USD.**

3.2.7 Wiring

In the Wiring Dimensioning section (2.2.9) , it has already been mentioned that those are approximate calculations, as the exact values for distances and generator placement are not available at this moment. For this reason, it has been decided that undergoing precise budget calculations with the stated length approximate values may not be very useful, as those values will probably change. However, after studying several similar off grid projects, it has been noticed that wiring usually covers a range between 2%-4% of the total hardware costs. Despite this, these values are for projects that need wiring for the whole installation, whereas in Mpaga all the AC wiring is already installed and used by the power delivered through the generators. For this reason, a 2% of the total hardware cost has been determined as a reasonable estimate value. Considering this, the wiring would represent an initial capital **cost of 8340 $.**

3.2.8 Hardware Cost Distribution

The following table and figure summarize the initial capital cost values obtained in the previous chapters.

PV Modules	Battery Bank	DC Combiners	Charge Controllers	Inverter	Mounting Racks	Wiring
203.320 $	115.294 $	4.400 $	21.000 $	45.000 $	18.000 $	8.340 $

Table 30. Hardware Cost Summary

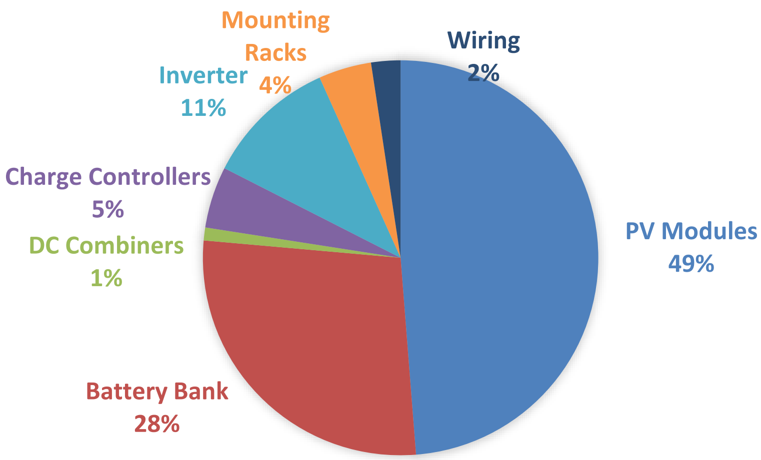


Figure 34.Mpaga Hardware Cost Distribution

3.3 Transportation and Installation

3.3.1 Transportation

One of the most troubling issues when designing the solar installation in Mpaga is the fact that the community is in a remote area. This problem becomes especially relevant when it comes to technical equipment, such as solar panels or batteries, as even if the site was near main Gabonese cities the supply of this kind of devices is quite uncompetitive. For this reason, it has been decided that the equipment will be shipped from Europe, where it can be purchased at lower prices, to the city of Port-Gentile in a container carrying commercial ship. The two main ports that supply the African routes are Port of Barcelona and the Port of Valencia, both in Spain. It has been chosen that the equipment will be shipped from the Port of Barcelona. Once the equipment is delivered to Port Gentile in the Commercial Containers, a smaller boat will deliver them to Mpaga by sailing the Ogooue River upstream. While the official price of shipping material in a container ship from one port to another can be precisely estimated if the weight and volume of the product is known, the price of getting this equipment from Port Gentil to Mpaga will be based on a probably less accurate estimation, as no official information is available.

The first step to calculate the cost of transportation is knowing the total weight and volume occupied by our load. The components with a higher impact in this calculation will be the solar panels and the batteries, and to a much lesser extent, the Solar Racks. Component weight and volume properterties are obtained from the provided data sheets in the annex.

Solar Panels:

$$1050\,panels \cdot 0{,}0654\,\frac{m^3}{panel} = 68{,}67\,m^3$$

$$1050\,panels \cdot 18{,}2\,\frac{kg}{panel} = 19.110\,kg$$

Batteries:

$$840\,batteries \cdot 21\,\frac{kg}{charged\ battery} = 17.640\,kg$$

$$840\,batteries \cdot 0{,}011\,\frac{m^3}{battery} = 9{,}5\,m^3$$

This would mean that 36.750 kg and 78,17 m^3 would be needed to transport the battery bank and the solar panels. The solar racks come in very compact packages, and it is estimated that 40.000kg and 85 m^3 should be enough to also fit these in. The rest of the components (inverter, wiring, charge controllers, etc..) do not represent strongly relevant amounts of weight and volume. For this reason , it has been determined that the needed capacity storage in the container ship would be of 45 t and 90 m^3.

The company *iContainers* will **charge 74.900 $ USD** for these amounts, and will deliver the charge in 25-30 days from Barcelona to Port Gentile.

According to the information provided by EWB Gabon, the total cost of getting to Mpaga on a small boat is of 400 $ USD. These boats, however, would not be an appropriate way of delivering the load to Mpaga given their little available space. It has been estimated that 6000 $ USD should be enough to deliver the load to the community of Mpaga. This is only an estimation, and this value, as well as the economic balance, should be updated before undergoing the physical installation.

3.3.2 Installation Costs

Once again, the cost of hiring workers and qualified installers in Gabon is not officially available, and both the Foundation as EWG Gabon have not been able to provide verified values regarding this matter. So, to obtain a reliable estimation, the average installation cost provided by the US National Renewable Energy Laboratory has been considered, and then modified according to the community's situation. The following figure provides average costs for Projects developed in the US depending on the system size.

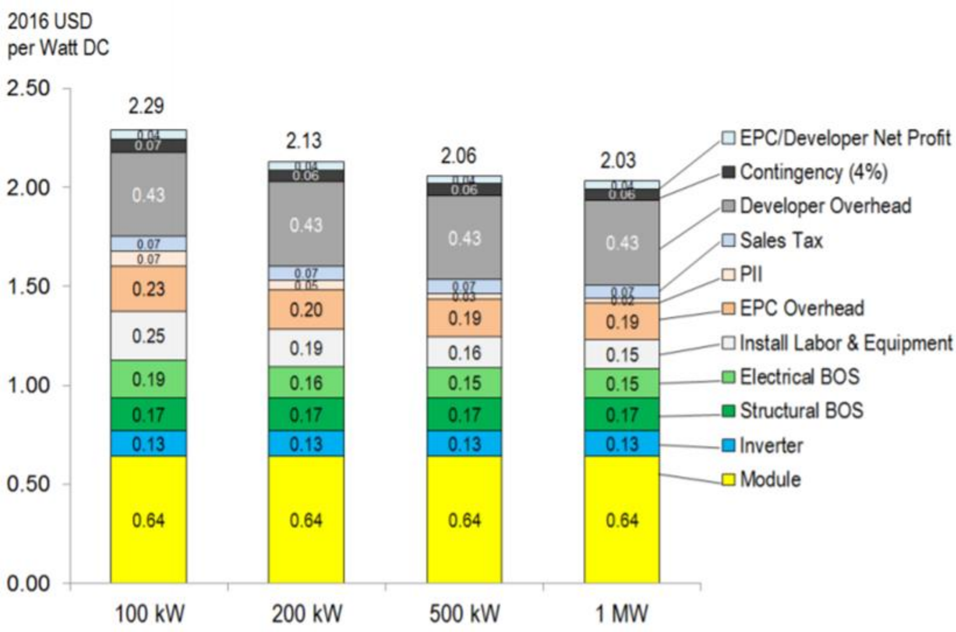


Figure 35. NREL Costs for US Solar Projects.

If the prices in the previous figure are considered, Mpaga's Installation Labour costs would be of something around 0,19 $/W installed (for 200kW size systems) and 0,16 $/W installed (for 500kW size systems). However, this considers US labour prices and full project installations. In Mpaga, besides adding a few fuses and circuit breakers, no modifications need to be done for the AC section. Considering this, an installation cost of 0,08 $/W has been determined. This would mean an initial installation cost of **24.000 $ USD.**

3.4 Total Cost and Economic Indicators

The following table represents the site's cash flow throughout its 25 years of life-time. The years are set as rows, and the different costs and incomes are represented in the table's columns. Red cells indicate a cost or a negative annual or accumulated cash flow, whereas green cells indicate income or positive cash flows. A 10% variation has been considered for the diesel consumption. As it may be observed from the table, the whole installation of Mpaga would have a **pay-back time of approximately 7 years**, which is a more than acceptable figure considering the project's lifetime.

Year	Initial Capital	Battery Replacement	Used Diesel	O&M	Diesel Savings	Flux T	Flux ACum
0	520254		0		0	-$520.254,00	-$520.254,00
1	0	0	8825	740	78000	$68.435,00	-$451.819,00
2	0	0	8536	740	78000	$68.724,00	-$383.095,00
3	0	0	9051	740	78000	$68.209,00	-$314.886,00
4	0	0	8890	740	78000	$68.370,00	-$246.516,00
5	0	0	8943	740	78000	$68.317,00	-$178.199,00
6	0	0	9380	740	78000	$67.880,00	-$110.319,00
7	0	0	8750	740	78000	$68.510,00	-$41.809,00
8	0	0	8691	740	78000	$68.569,00	$26.760,00
9	0	0	9518	740	78000	$67.742,00	$94.502,00
10	0	115000	9001	740	78000	-$46.741,00	$47.761,00
11	0	0	9202	740	78000	$68.058,00	$115.819,00
12	0	0	9425	740	78000	$67.835,00	$183.654,00
13	0	0	8605	740	78000	$68.655,00	$252.309,00
14	0	0	8125	740	78000	$69.135,00	$321.444,00
15	0	0	8015	740	78000	$69.245,00	$390.689,00
16	0	0	9574	740	78000	$67.686,00	$458.375,00
17	0	0	8261	740	78000	$68.999,00	$527.374,00
18	0	0	9118	740	78000	$68.142,00	$595.516,00
19	0	0	8309	740	78000	$68.951,00	$664.467,00
20	0	115000	9054	740	78000	-$46.794,00	$617.673,00
21	0	0	9239	740	78000	$68.021,00	$685.694,00
22	0	0	8092	740	78000	$69.168,00	$754.862,00
23	0	0	8545	740	78000	$68.715,00	$823.577,00
24	0	0	8382	740	78000	$68.878,00	$892.455,00
25	0	0	8509	740	78000	$68.751,00	$961.206,00

Table 31. 25-year Cash-Flow Table

The following graph portrays the accumulated cash flow evolution. The slight decreases around years 9 and 18 correspond to the battery bank replacement costs.

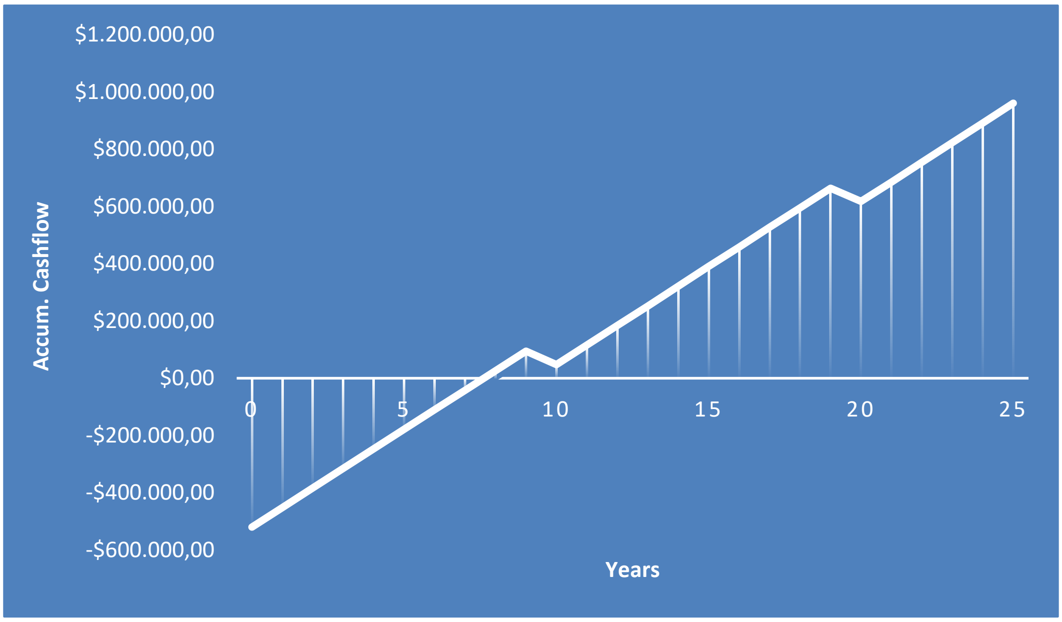


Figure 36. 25-Year Accumulated Cash Flow Graph

To calculate some other economic indicators, Gabon's Inflation Index must be considered. According to the following graph provided by the IMF, a 2% rate can be a sensible value to use as an estimation.

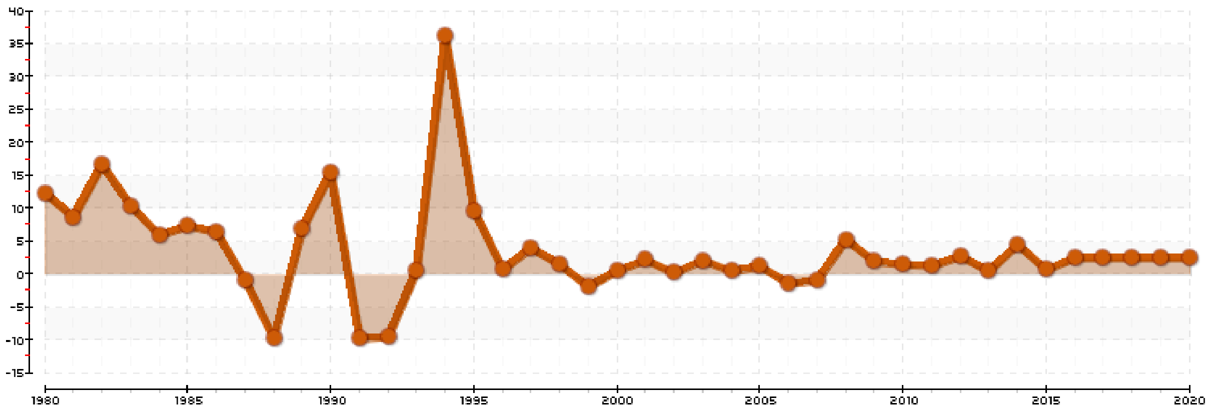


Figure 37. Gabon's Inflation Index Progression (FMI)

The following table provides the Net Present Value and Internal Rate of Return of the site if the previous cash-flow prevision is used. If the only criteria used to determine a project's economic viability is the NPV, the project should be carried out as long as this indicator's value is positive. However, projects usually have initial investment and pay-back time restrictions. Given it has already been confirmed that the project's pay-back time is acceptable, the fact that the NPV of the project considering its 25-year lifetime is positive could be enough to affirm that it is financially wise to execute the project. Additionally, the intern rate of return is also substantially higher than the expected inflation index, which is also a favourable economic indicator. For these reasons, the project can be considered as financially viable.

NPV	$642.637,73
IRR	11%

Table 32. NPV and IRR Economic Indicators

CONCLUSIONS

The design of a solar off grid installation for the community of Mpaga considering its social and economic context is the main goal of this thesis, aiming to help such community become more independent and lower its carbon footprint. Considering all the social, technical, geographical, logistical and economical aspects involved in a project of this dimension has been considered essential for the project to remain realistically viable. The thesis' main question is if after considering all the previously stated factors, the project is still economically convenient for the NGO managing the community: ESPACE AFRIQUE.

First, research on Mpaga's inhabitants' habits and lifestyle, as well as the village's facilities, allowed for a load electrical profile to be determined. The load profile for Mpaga follows the typical rural community double-peak pattern. Once the community's demands were clear, an accurate dimensioning of the energetical installation was undergone. It has been determined that for an off-grid installation to remain majorly renewable, the installed power must substantially oversize the load demand profile. Firstly, the most suitable electrical circuit for the community's energetic requirements has been determined. Afterwards, a cost-efficiency and performance analysis for every component in the circuit has been carried out to determine the commercial models that need to be bought, as well the distribution between components. The final dimensioning of the installation was done by firstly undergoing a thorough work of investigation and calculation to parametrise correctly all the components and the project's constraints, and afterwards using energetic optimizers to obtain the most convenient dimension and distribution for some of the main devices.

As stated before, the aim is to consider all phases involved in the realisation of the project. Therefore, besides the electrical hardware costs, several other key factors have been considered. These include ship transportation from Barcelona to Mpaga, installation costs, appropriate maintenance schedule of the site, as well as other social considerations such as over-load management or local institutionalisation.

The study and dimensioning of the site does indeed have some limitations. For instance, the wiring analysis should be revised as no official data for specific distances has been provided neither EWB or Espace Afrique. Also, due to a lack of official pricing, the transportation costs from Port-Gentile to Mpaga have also been estimated based on the cost of traveling this route on a smaller boat. However, the range of values at which these factors could stand will not, under any circumstance, have a relevant or decisive impact on the project's viability.

After analysing the costs all the previously mentioned factors imply, and performing the economic viability study, it is determined that the installation of the designed solar energy system for Mpaga is strongly convenient for both the community and ESPACE AFRIQUE, regardless the point of view. Firstly, and most important, it is economically viable: It drastically reduces the annual fuel costs, allowing for the investment to be recovered in less than 8 years, and producing a substantial annual profit that can be reinvested in the community during the following 17 years, hence improving the villager's lifestyle. Secondly, it brings energetic independency to the community, as the need for constant fuel supply is significantly decreased. Last, but not least, Mpaga's carbon-footprint will be reduced to less than a tenth than its actual value, and further community growth will be based on renewable and sustainable sources of energy.

For these reasons, the next recommended steps for ESPACE AFRIQUE are revising the proposed design and updating the few factors that have been left as estimations. Afterwards, looking for investors or submitting the appropriate paper-work for the Foundation to approve the initial investment is a necessary phase. Finally, local institutionalisation and training are the last steps before the installation's hardware equipment can be ordered and shipped, allowing Mpaga's Solar Microgrid to become a reality.

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Complementary Bibliography

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ANNEX

Espace Afrique Mpaga Health-Centre Project

Full Project Application

1. Nom du projet:	Réhabilitation des infrastructures socio-sanitaires en zone rurale du département de Bendjè (province de l'Ogooué Maritime)

2. Soumis par:	Fondation Espace Afrique	**Date:**	

3. Description du projet

Fournir une brève description du projet (emplacement, la portée, etc.)

Notre ONG, Fondation Espace Afrique, opère depuis 1992 des projets humanitaires qui s'adressent aux populations des villages enclavés du département de Bendjè dans la province de l'Ogooué Maritime. Ces villages localisés en bordure du fleuve Ogooué, souffrent cruellement d'un manque d'accès aux services sociaux de base comme la santé, l'eau potable, ou même l'éducation.

Fondation Espace Afrique a construit, équipé et gère depuis 1993 des infrastructures socio-sanitaires qui visent à répondre aux besoins des populations rurales :

- Une école primaire avec internat ; une centaine d'enfants en moyenne sont scolarisés et hébergés au Complexe Scolaire Jules Djeky de Mpaga. Le village accueille également un collège public (CES) avec une soixantaine d'élèves.

- Un centre médical qui offre gratuitement les soins aux populations des villages du département et de la province de l'Ogooué Maritime. La structure est dotée de 15 lits d'hospitalisation et d'une pharmacie. La population bénéficiant de l'accès aux soins grâce au centre médical est estimée à 3000 personnes. Ces populations vivent dans une soixantaine de villages autour de Mpaga et se déplacent en pirogue.

- Des infrastructures et matériels annexes pour le fonctionnement du complexe.

Nous sollicitons l'appui technique d'ISF Gabon pour nous aider à trouver des solutions pour l'amélioration des conditions d'hygiène et de santé des populations rurales que nous servons et des élèves du complexe scolaire Jules Djeky. Nous souhaiterions qu'ISF nous accompagne sur le terrain pour :

1. La rénovation et l'assainissement du bâtiment abritant le centre médical. En effet, l'état actuel du bâtiment ne nous permet plus d'accueillir dans les meilleures conditions nos populations rurales déjà vulnérables. Nous voulons particulièrement trouver une solution au problème de l'invasion des chauves-souris qui se sont logées dans le plafond du centre médical et ont provoqué la dégradation et l'insalubrité du bâtiment.

2. La construction de latrines durables et adaptées au contexte rural du projet. Nous voulons également former les villageois à la construction, l'entretien et la maintenance de ce type d'installation.

4. Type de projet

Oui/Non	Catégories	Description
	Approvisionnement en eau	Le village est doté de 2 châteaux d'eau. Les villageois se rendent aussi au fleuve.
	Gestion des déchets	Une fosse a été creusée dans lequel les déchets sont jetés puis brûlés. Certains déchets comme les boîtes de conserves ne peuvent pas être détruits
	Structures	
	Génie Civil	
	Energie	Le village est alimenté en électricité par 2 groupes électrogènes d'une capacité de 150 et 80 KVA. Fondation Espace Afrique finance et gère ces équipements. Cette source d'énergie est très coûteuse. Nous recherchons un technicien compétent pour la maintenance périodique

		de ces machines.
	Education	Le village a une école primaire avec internat, le Complexe Scolaire Jules Djeky, entièrement financé et géré par Fondation Espace Afrique. Les enfants (78 sont inscrits cette année) sont gratuitement pris en charge et hébergés sur place. L'école a ouvert en 1996. Le Collège d'Enseignement Secondaire de Mpaga a ouvert en 1998 et accueille une soixantaine d'enfants
	Autres	

5. Informations sur la communauté bénéficiaire du projet

ISF-Gabon sera impliqué dans des projets où la communauté est bien organisée et motivée à contribuer au projet. Il est fortement recommandé que la communauté soit organisée en une association (organisme communautaire) qui pourrait suivre le projet et assurer sa viabilité à long terme.

Le village abritant le projet est peuplé d'environ 300 habitants dont les trois-quarts sont les élèves de l'école primaire et du collège qui vivent à l'internat. L'éducation et dans une moindre mesure l'agriculture constituent les principales activités du village.

Fondation Espace Afrique organise la maintenance et l'entretien des infrastructures installées sur le site. Le responsable de maintenance coordonne une équipe constituée d'un électricien, un plombier soudeur, un menuisier, et de mécaniciens. C'est donc au niveau du village que seraient effectuées les activités de maintenance et de suivi des actions réalisées dans le cadre d'un appui d'ISF-Gabon.

6. Quels sont les besoins de la communauté et leur situation financière?

Les besoins de la communauté sont **le renforcement de leurs capacités pour leur permettre de s'organiser et d'accroître leur autonomie économique**.
Les villages du département de Bendjé souffrent énormément d'une situation d'enclavement qui freine le développement d'activités agricoles viables et génératrices de revenus. Le coût du transport est très élevé, les embarcations sont rares, ce qui limite l'accès aux marchés de Port-Gentil et pénalise les activités commerciales.

De plus, les villageois doivent faire face au grave problème de destruction des champs par les animaux sauvages qui entraîne des pertes économiques pouvant aller jusqu'à 70% des récoltes.

Il faut ajouter à ces facteurs de vulnérabilité économique, le problème de l'accès difficile des populations aux infrastructures médicales et hospitalières fiables, ainsi que la pénurie de médicaments dans les rares centres de santé existant en zone rurale.
De plus, l'accès à l'eau potable reste un problème majeur de santé publique dans les villages. Et dans le cas où des puits et parfois des forages sont construits, le problème de la qualité de l'eau se pose.

Compte tenu de cet environnement socio-économique difficile, les communautés rurales du département de Bendjé sont dans une situation financière précaire et continuellement fragilisée.

7. Apport du projet à la communauté

Comment le projet impactera la communauté?

Le projet impactera la communauté à deux niveaux :

1. Sur le plan de la prévention sanitaire et de l'amélioration de l'état de santé des communautés concernées. Il

Full Project Application

faut rappeler que le centre médical est le seul centre de santé équipé dans la zone. Son approvisionnement en médicaments se fait chaque trimestre.

2. L'autonomisation des populations par l'acquisition de compétences dans la construction et l'entretien des infrastructures.

Quel est le nombre estimé de personnes qui bénéficieraient directement du projet?

Nous estimons le nombre de personnes directement bénéficiaires de la construction des latrines à 200 personnes vivant sur place (essentiellement les élèves et d'autres habitants du village).

La réouverture du centre médical de Mpaga pourra bénéficier à l'ensemble de la population du département de Bendjè voire au-delà, qu'y s'y rend pour bénéficier de soins gratuits et de médicaments. Cette population est estimée entre 3000 et 5000 habitants.
Le centre médical accueille en moyenne par mois 150 patients dont une dizaine de cas d'hospitalisation.

Quel est le nombre estimé de personnes qui bénéficieraient indirectement du projet?

Nous aimerions également étudier dans quelle mesure la construction d'un certain type de latrines pourrait être répliquée au niveau des autres villages et apporter des solutions durables aux questions d'hygiène et d'assainissement en zone rurale.

8. Brève description des objectifs du projet

Comment ce projet peut-il améliorer les conditions de vie de la communauté?

Notre ONG voudrait pouvoir de manière durable encourager les bonnes pratiques en matière d'hygiène et d'assainissement, en particulier dans les écoles et les structures de santé. En effet, de nombreuses maladies et pathologies comme la diarrhée, le choléra ou encore le paludisme, sont liées à un milieu insalubre et à une mauvaise gestion des déchets.

En agissant sur la prévention, le renforcement des capacités des communautés bénéficiaires (transfert de savoir-faire et de compétences), mais aussi en assurant leur participation, ce projet permettrait auxdites communautés de s'approprier réellement leur santé.

Ainsi, l'appui d'ISF-Gabon nous donnerait les moyens de poser des bases solides d'un projet sanitaire qui répond aux besoins quotidiens de communautés qui souffrent déjà d'un accès limité aux soins de santé primaire.

Dans le but de pérenniser cette action, Fondation Espace Afrique s'emploiera à mener sur le terrain des programmes d'information, d'éducation et de sensibilisation des populations sur les questions d'hygiène et d'assainissement.

9. Y a t-il un projet similaire dans la région?	Oui		Non	

Décrire les organisations qui ont participé et le niveau de participation de la communauté?

Il n'existe pas à notre connaissance de projets menés dans les villages du département de Bendjè en matière d'hygiène et d'assainissement.

Full Project Application

Les villageois construisent eux-mêmes des latrines très simples (de simples fosses creusées) et utilisent des techniques peu pérennes et surtout peu fiables en matière d'hygiène pour préserver ce type d'installation.

Il existe des centres de santé mais ils sont peu équipés et souvent dépourvus de médicaments. Le personnel de santé est rare en zone rurale.

Quelles sont les autres organisations qui ont participé et quel était leur niveau de participation ?

Le Conseil Départemental de Bendjè a financé la construction de 8 centres de santé dans le département.
Le Centre médical de Mpaga reçoit occasionnellement des dons de médicaments du Conseil départemental. Ce dernier a également financé la construction de la deuxième aile du bâtiment.

10. Estimation de la durée du projet

Phase	Durée

11. Quel serait le rôle des Ingénieurs Sans Frontières?

Apporter un appui technique à la Fondation pour lui permettre de réhabiliter le centre médical et de construire des latrines.

1. Evaluation des travaux et réhabilitation du centre médical et des latrines
2. Formation des villageois à la construction et la maintenance des installations
3. Recommandations pour la recherche de solutions durables et écologiques pour traiter le problème de l'invasion des chauves-souris dans les bâtiments

Quelles sont les compétences que l'ISF-Gabon peut apporter?

- Compétences techniques pour la gestion et réalisation du chantier de réhabilitation du centre médical Compétences techniques dans l'installation de système de toilettes type latrine.
- D'une manière générale définir et apporter les compétences techniques nécessaires à la réalisation des chantiers.

12. Quel serait le rôle de la communauté?

Combien de membres de la communauté participeraient au projet?

Les villageois
L'équipe de maintenance de Fondation Espace Afrique composée d'un électricien, un plombier soudeur, un menuisier, et de plusieurs mécaniciens.

Quelles seraient leurs contributions?

Main d'oeuvre
Participation pour les travaux de menuiserie, plomberie, électricité.

13. Le projet est-il durable?

Expliquez ce qui rend ce projet durable

Ce qui rend ce projet durable est la capacité des communautés à entretenir elles-mêmes les installations.

CS6K-290MS DATASHEET


NEW

CanadianSolar

ALL-BLACK
CS6K-285|290|295 MS

Canadian Solar's All-Black CS6K-MS modules enhance the aesthetics of our 5 bus bar mono modules while providing a higher energy output. All-Black CS6K-MS modules are equipped with Mono-PERC cells, a dark colored backsheet and a black frame.

KEY FEATURES

- 9 % more power than conventional modules
- Excellent performance at low irradiance of up to 97.5 %
- Improved energy production due to low temperature coefficients
- IP67 junction box for long-term weather endurance
- Heavy snow load up to 6000 Pa, wind load up to 4000 Pa *

25 years linear power output warranty

10 years product warranty on materials and workmanship

MANAGEMENT SYSTEM CERTIFICATES*
ISO 9001:2008 / Quality management system
ISO 14001:2004 / Standards for environmental management system
OHSAS 18001:2007 / International standards for occupational health & safety

PRODUCT CERTIFICATES*
IEC 61215 / IEC 61730: VDE / CE / MCS / CEC AU
UL 1703 / IEC 61215 performance: CEC listed (US)
UL 1703: CSA
Take-e-way

* As there are different certification requirements in different markets, please contact your local Canadian Solar sales representative for the specific certificates applicable to the products in the region in which the products are to be used.

CANADIAN SOLAR INC. is committed to providing high quality solar products, solar system solutions and services to customers around the world. As a leading PV project developer and manufacturer of solar modules with over 17 GW deployed around the world since 2001, Canadian Solar Inc. (NASDAQ: CSIQ) is one of the most bankable solar companies worldwide.

*For detail information, please refer to Installation Manual.

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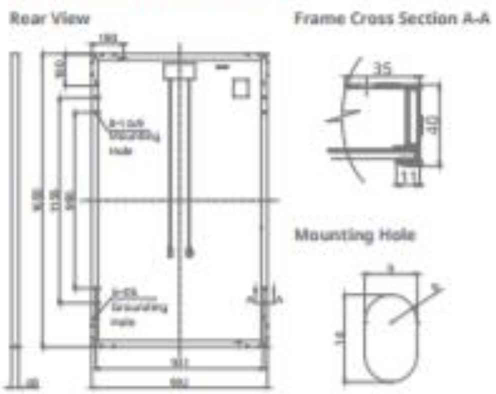
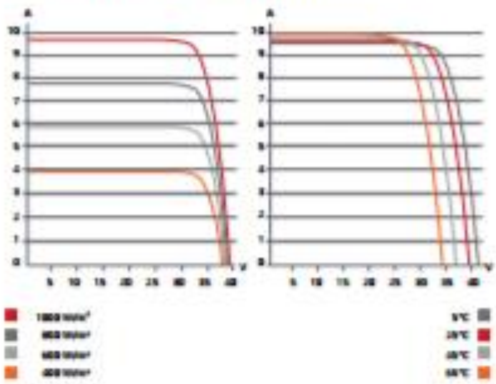
ENGINEERING DRAWING (mm)



ALL-BLACK CS6K-295MS / I-V CURVES



ELECTRICAL DATA | STC*

All-Black CS6K	285MS	290MS	295MS
Nominal Max. Power (Pmax)	285 W	290 W	295 W
Opt. Operating Voltage (Vmp)	31.9 V	32.1 V	32.3 V
Opt. Operating Current (Imp)	8.94 A	9.05 A	9.14 A
Open Circuit Voltage (Voc)	39.1 V	39.3 V	39.5 V
Short Circuit Current (Isc)	9.59 A	9.67 A	9.75 A
Module Efficiency	17.41%	17.72%	18.02%
Operating Temperature	-40°C ~ +85°C		
Max. System Voltage	1000 V (IEC) or 1000 V (UL)		
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)		
Max. Series Fuse Rating	15 A		
Application Classification	Class A		
Power Tolerance	0 ~ + 5 W		

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline, 6 inch
Cell Arrangement	60 (6×10)
Dimensions	1650×992×40 mm (65.0×39.1×1.57 in)
Weight	18.2 kg (40.1 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP67, 3 diodes
Cable	4 mm² (IEC) or 4 mm² & 12 AWG 1000 V (UL), 1000 mm (39.4 in)
Connectors	T4 series or PV2 series
Per Pallet	26 pieces, 520 kg (1146.4 lbs)
Per Container (40' HQ)	728 pieces

ELECTRICAL DATA | NOCT*

All-Black CS6K	285MS	290MS	295MS
Nominal Max. Power (Pmax)	207 W	210 W	213 W
Opt. Operating Voltage (Vmp)	28.8 V	29.0 V	29.2 V
Opt. Operating Current (Imp)	7.19 A	7.25 A	7.30 A
Open Circuit Voltage (Voc)	36.0 V	36.2 V	36.4 V
Short Circuit Current (Isc)	7.65 A	7.74 A	7.83 A

* Under Nominal Operating Cell Temperature (NOCT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.39 % /°C
Temperature Coefficient (Voc)	-0.30 % /°C
Temperature Coefficient (Isc)	0.053 % /°C
Nominal Operating Cell Temperature	45±2 °C

PERFORMANCE AT LOW IRRADIANCE

Outstanding performance at low irradiance, with an average relative efficiency of 97.5 % from irradiances, between 1000 W/m² and 200 W/m² (AM 1.5, 25°C).

The specification and key features described in this datasheet may deviate slightly and are not guaranteed. Due to on-going innovation, research and product enhancement, Canadian Solar Inc. reserves the right to make any adjustment to the information described herein at any time without notice. Please always obtain the most recent version of the datasheet which shall be duly incorporated into the binding contract made by the parties governing all transactions related to the purchase and sale of the products described herein.

Caution: For professional use only. The installation and handling of PV modules requires professional skills and should only be performed by qualified professionals. Please read the safety and installation instructions before using the modules.

PARTNER SECTION

ETSEIB

Surrette Rolls S105 DATASHEET

Rolls FLOODED DEEP CYCLE BATTERIES

S-105

12 VOLTS

CONTAINER:	Polypropylene
COVER:	Polypropylene
TERMINALS:	Universal terminal
HANDLES:	Integrated top cover

WEIGHT DRY:	16 kg	35 Lbs.
WEIGHT WET:	21 kg	46 Lbs.
LENGTH:	276 mm	11 Inches
WIDTH:	171 mm	6 3/4 Inches
HEIGHT:	238 mm	9 3/8 Inches

6 Cell

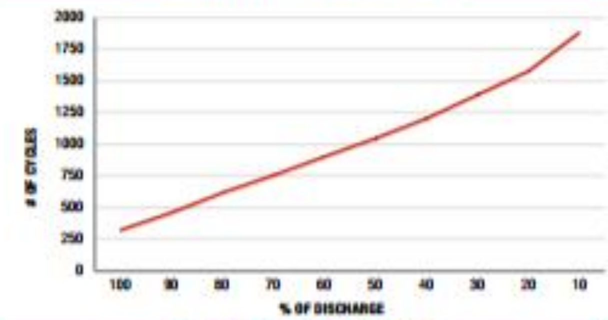
Certified System ISO 9001 Quality

COLD CRANK AMPS (CCA):	0°F / -17.8°C	500
MARINE CRANK AMPS (MCA):	32°F / 0°C	625
RESERVE CAPACITY (RC @ 25A):		135 Minutes

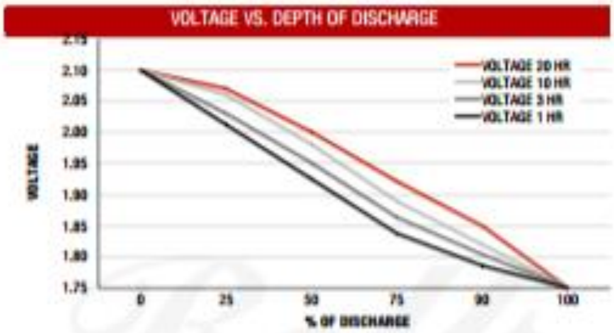
CAPACITY 85 AH

HOUR RATE:	SPECIFIC GRAVITY	CAPACITY / AMP HOUR	CURRENT / AMPS
@ 100 HOUR RATE	1.280	106	1.06
@ 20 HOUR RATE	1.280	85	4.25
@ 15 HOUR RATE	1.280	80	5.33
@ 12 HOUR RATE	1.280	76	6.33
@ 10 HOUR RATE	1.280	72	7.20
@ 8 HOUR RATE	1.280	71	8.88
@ 6 HOUR RATE	1.280	70	11.67
@ 5 HOUR RATE	1.280	69	13.80
@ 4 HOUR RATE	1.280	55	13.75
@ 3 HOUR RATE	1.280	50	16.67
@ 2 HOUR RATE	1.280	43	21.50
@ 1 HOUR RATE	1.280	31	31.00

CYCLE LIFE VS. DEPTH OF DISCHARGE



VOLTAGE VS. DEPTH OF DISCHARGE



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SPEC 01

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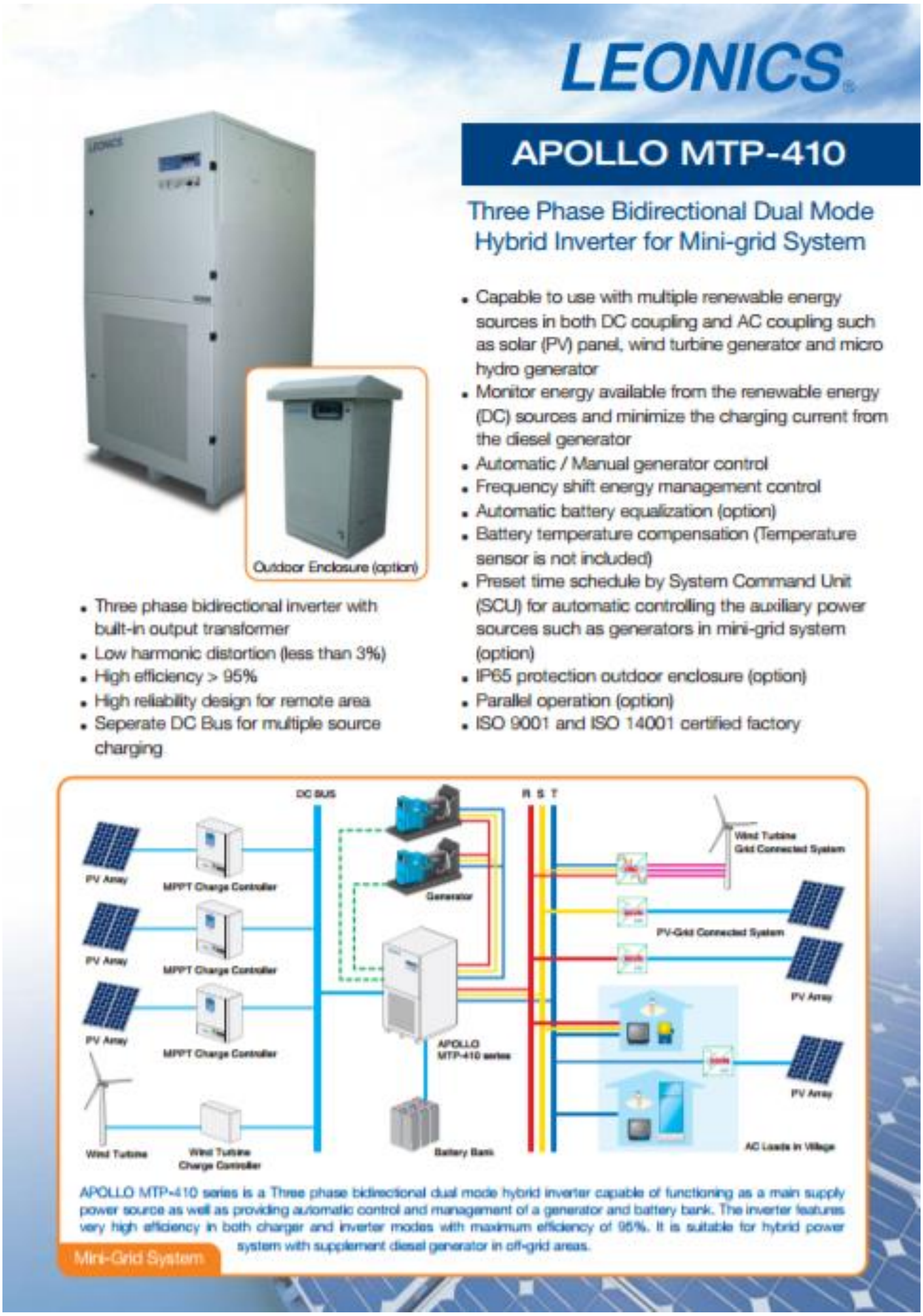
LEONICS APOLLO MTP417F DATASHEET


LEONICS

APOLLO MTP-410

Three Phase Bidirectional Dual Mode Hybrid Inverter for Mini-grid System

- Capable to use with multiple renewable energy sources in both DC coupling and AC coupling such as solar (PV) panel, wind turbine generator and micro hydro generator
- Monitor energy available from the renewable energy (DC) sources and minimize the charging current from the diesel generator
- Automatic / Manual generator control
- Frequency shift energy management control
- Automatic battery equalization (option)
- Battery temperature compensation (Temperature sensor is not included)
- Preset time schedule by System Command Unit (SCU) for automatic controlling the auxiliary power sources such as generators in mini-grid system (option)
- IP65 protection outdoor enclosure (option)
- Parallel operation (option)
- ISO 9001 and ISO 14001 certified factory

Outdoor Enclosure (option)

- Three phase bidirectional inverter with built-in output transformer
- Low harmonic distortion (less than 3%)
- High efficiency > 95%
- High reliability design for remote area
- Seperate DC Bus for multiple source charging

APOLLO MTP-410 series is a Three phase bidirectional dual mode hybrid inverter capable of functioning as a main supply power source as well as providing automatic control and management of a generator and battery bank. The inverter features very high efficiency in both charger and inverter modes with maximum efficiency of 95%. It is suitable for hybrid power system with supplement diesel generator in off-grid areas.

Mini-Grid System

LEONICS®

APOLLO MTP-410 series Three Phase Bidirectional Dual Mode Hybrid Inverter for Mini-Grid System

MODEL		MTP-411E	MTP-412E	MTP-413E	MTP-411F	MTP-412F	MTP-413F	MTP-414F	MTP-415F	MTP-416F	MTP-417F	MTP-418F	MTP-419F	MTP-4110F	MTP-4111H	MTP-4113H	MTP-4115H	MTP-4117H
RATED POWER		10 kW	15 kW	25 kW	10 kW	15 kW	25 kW	30 kW	45 kW	60 kW	75 kW	90 kW	100 kW	120 kW	150 kW	200 kW	250 kW	300 kW
BATTERY	Nominal Voltage	120 Vdc			240 Vdc										480 Vdc			
	Max.charging current	56 A	84 A	130 A	28 A	42 A	72 A	84 A	125 A	168 A	200 A	250 A	280 A	335 A	200 A	280 A	350 A	418 A
	Max. battery current	114 A	170 A	284 A	57 A	85 A	142 A	170 A	255 A	340 A	425 A	510 A	570 A	680 A	425 A	570 A	710 A	850 A
EXTERNAL DC CHARGER	Nominal voltage	120 Vdc			240 Vdc										480 Vdc			
	Maximum current	100 A	100 A	200 A	57 A	60 A	100 A	100 A	200 A	300 A	300 A	400 A	400 A	400 A	300 A	400 A	400 A	500 A
AC INPUT FROM GENERATOR	Recommended generator power	> 20 kW	> 30 kW	> 50 kW	> 20 kW	> 30 kW	> 50 kW	> 60 kW	> 90 kW	> 120 kW	> 150 kW	> 180 kW	> 200 kW	> 240 kW	> 300 kW	> 400 kW	> 500 kW	> 600 kW
	Voltage	380 / 400 / 415 Vac (L-L), 220 / 230 / 240 Vac (L-N) ± 10%																
	Phase	Three phase																
	Frequency	50 / 60 Hz ± 3 Hz																
	Max. AC current	32 A	48 A	80 A	32 A	48 A	80 A	96 A	144 A	191 A	240 A	287 A	319 A	382 A	478 A	637 A	796 A	955 A
	Automatic start / stop	Relay dry contact 10 A (2 sets of ACC contact for 2 generators)																
AC OUTPUT	Voltage	380 / 400 / 415 Vac (L-L), 220 / 230 / 240 Vac (L-N)																
	Voltage regulation	± 3% (steady load), < 7% at 100% step load within 0.1 sec.																
	Phase	Three phase																
	Frequency	50 / 60 Hz ± 0.1% (auto sensing)																
	Wave form	Pure sine wave																
	THD	total < 3%																
	Max. surge current	200%																
	Max. AC current	15.2 A	22.7 A	37.8 A	15.2 A	22.7 A	37.8 A	45.4 A	68.2 A	90.9 A	113.6 A	136.3 A	151.5 A	181.8 A	227.3 A	303 A	378.8 A	454.5 A
ISOLATION	Galvanic isolation	yes																
EFFICIENCY	Inverter peak efficiency	> 94%						> 95%										
PROTECTION		Over current, Over load, Short circuit, Over temperature, Over voltage, Under voltage																
INDICATOR	LED	External Charging, Bypass, Generator Running, Generator Failure,Stand by/Run, Inverter, Charging, Load on Inverter, Overload, Low Battery, High temperature, Fault																
	LCD display	Inverter (voltage, current, frequency, power, reactive power), Generator (voltage, current, frequency, power, reactive power), Battery (voltage, current, state of charge(%), charging current), Heat sink temperature, Battery temperature (option), Equalization date, Today DC Inverter Energy (Input, output) Today AC Inverter Energy (input, output), Accumulated DC energy (input, output), Accumulated AC Energy (input, output), System status, Time, Date, Data Log																
AUDIABLE ALARM		Low battery, Inverter fault, High temperature																
COOLING		Automatic cooling fan																
ENVIRONMENT	Temperature	0 - 45°C																
	Relative humidity	0 - 95 % (Non - condensing)																
DESIGN REGULATION	Standard	AS/NZ 3100:2002, IEC 61683 (for efficiency test)																
	Enclosure	IP31 (IP65 option)		IP54 (IP65 option)	IP31 (IP65 option)		IP54 (IP65 option)	IP31										
DIMENSION W x H x D (cm)	Control Unit	60 x 188 x 105								90 x 188 x 105		120 x 205 x 105			80x205x105	D1*: 550 / D2**: —	110 x 205 x 105	
	Transformer Unit	-								-		-			120x205x105	D1* / D2**	110 x 205 x 105	
WEIGHT (approx. in kg)	Control Unit	430	440	450	430	440	450	460	630	805	850	990	1,020	1,040	550	D1*: 550 / D2**: 775	775	775
	Transformer Unit	-	-	-	-	-	-	-	-	-	-	-	-	-	1,200	D1*: 1,320 / D2**: 1,220	1,300	1,500

D1* = 80 x 205 x 105 cm for control unit and 120 x 205 x 105 for transformer unit, D2** = 110 x 205 x 105 cm for control unit and transformer unit. Continuous product development is our commitment. In that manner, the above specifications may be changed without prior notice.

Authorized Distributor

LEO ELECTRONICS CO.,LTD.

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Authorized Dealer

P.LEN.BRO.INV.091 Rev.22.00/2015

SOLARCOM SCM24070 DATASHEET

LEONICS

SOLARCON SCM

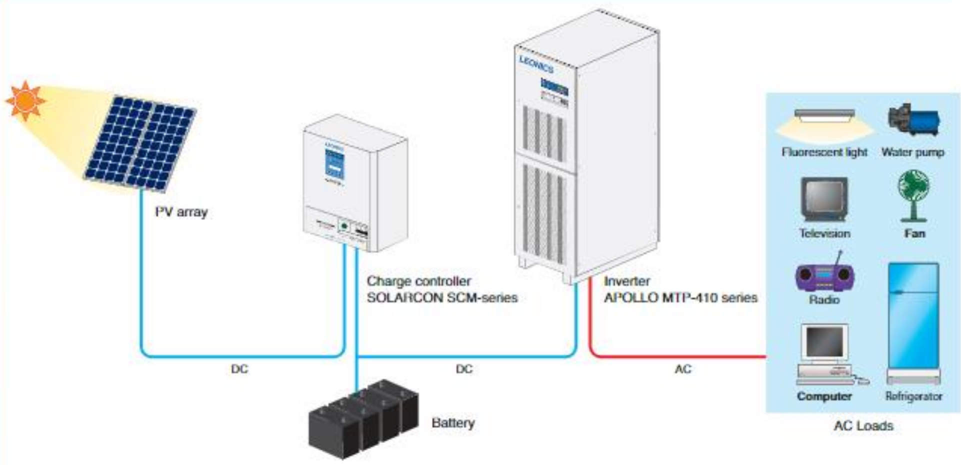
MPPT Charge Controller

Wall mount type

- Lightning surge protection
- Automatic cooling fan (outside enclosure)
- Comprehensive LED indication and LCD display
- Power and event data logger
- Reverse PV polarity protection and alarm (option)
- Wall mount or Rack mount 5U and 6U Case
- 2 years warranty (option for 3 and 5 years)
- ISO 9001 and ISO 14001 certified factory

- Advanced microprocessor control
- Maximum Power Point Tracking (MPPT)
- Boost regulator wide input range
- Automatic ON-OFF
- 3-step charging to provide quick and safe charging for battery
- Battery reverse polarity alarm
- Over charge and over discharge protection

Rack mount type



The SOLARCON SCM-series charge controller is the most sophisticate solar charger with PV Maximum Power Point Tracking (MPPT) algorithm. The charge controller equipped with advanced microprocessor control to get the maximum power from PV to charge battery with LCD display and front panel for easy and accurate setting more over the digital meter with 180 days power and event logger are inclusive

AC Solar Power System

LEONICS® SOLARCON SCM-series MPPT Charge Controller

SPECIFICATIONS

Wall Mount/Tower Model	SCM-12035	SCM-12070	SCM-120105	SCM-120140	SCM-24035	SCM-24070	SCM-240105	SCM-240140	SCM-360150	SCM-360300	SCM-360450	SCM-480150	SCM-480200	SCM-480300
Rack Mount Model	SCM-12035/RM	SCM-12070/RM	SCM-120105/RM		SCM-24035/RM	SCM-24070/RM	SCM-240105/RM	SCM-240140/RM						
INPUT (Configuration of PV in series within these voltage range)														
Vmp of PV*	85 - 110 Vdc				170 - 220 Vdc				255 - 330 Vdc			340 - 440 Vdc		
Tracking voltage range	48 - 110 Vdc				96 - 220 Vdc				144 - 330 Vdc			192 - 440 Vdc		
Voc of PV*	< 138Vdc				< 276 Vdc				< 414 Vdc			< 552 Vdc		
Maximum current	35 A	70 A	105 A	140 A	35 A	70 A	105 A	140 A	150 A	300 A	450 A	150 A	200 A	300 A
Maximum PV power**	3.4 kWp	6.88 kWp	10.3 kWp	13.7 kWp	6.88 kWp	13.7 kWp	20.6 kWp	27.5 kWp	45.5 kWp	91.0 kWp	136.5 kWp	60.6 kWp	82.6 kWp	121.1 kWp
OUTPUT (at 25°C)														
Nominal battery voltage	120 Vdc				240 Vdc				360 Vdc			480 Vdc		
Boost charging voltage	130.0 - 150.0 Vdc				260.0 - 300.0 Vdc				390.0 - 450.0 Vdc			520.0 - 600.0 Vdc		
Float charging voltage	120.0 - 140.0 Vdc				240.0 - 280.0 Vdc				360.0 - 420.0 Vdc			480.0 - 560.0 Vdc		
Low voltage alarm	100.0 - 120.0 Vdc				200.0 - 240.0 Vdc				300.0 - 360.0 Vdc			400.0 - 480.0 Vdc		
Low voltage cut off (signal)	99.0 - 119.0 Vdc				198.0 - 238.0 Vdc				297.0 - 357.0 Vdc			396.0 - 476.0 Vdc		
Reconnect voltage (signal)	115.0 - 135.0 Vdc				230.0 - 270.0 Vdc				345.0 - 405.0 Vdc			460.0 - 540.0 Vdc		
BATTERY														
Type	Deep cycle lead acid (LA)													
EFFICIENCY														
Charger peak efficiency	> 98%													
PROTECTION														
Protection	PV transient voltage surge, High battery voltage, Low battery voltage, Over temperature, Over charging													
Alarm	Battery reverse polarity													
INDICATOR														
LED	Battery level, PV voltage level, Operation status, Alarm													
LCD	Digital meter, 180 days power and event logger													
COMMUNICATION INTERFACE														
RS-232	DB-9 connector													
RS-485	Operate with RS-485 adaptor (option)													
Dry contact signal	Charger fail and low battery voltage disconnected													
SYSTEM														
Control	Automatic cooling fan, Maximum Power Point Tracking (MPPT)													
Temp. compensation range	-5 to 7 mV / cell / celsius (option)													
OPERATING CONDITION														
Temperature	0 - 45˚C													
Relative humidity	0 - 95% (non-condensing)													
DIMENSION (W x H x D) (approximate in cm.)														
Wall mount case	42 x 53 x 24		50 x 64 x 26.6		42 x 53 x 24		50 x 64 x 26.6		-					
Rack mount case	48.2 x 22.2 x 64.5 (5U)		48.2x28.2x64.5(6U)	-	48.2 x 22.2 x 64.5 (5U)		48.2 x 28.2 x 64.5 (6U)		-					
Tower case	-								60 x 210 x 100			60 x 210 x 100		
WEIGHT (approximate in kg.)														
Wall mount case	24	27	40	48	23	30	34	38	-	-	-	-	-	-
Rack mount case	25	28	41	-	24	31	37	40	-	-	-	-	-	-
Tower case									356	400	419	400	419	460

*The Vmp and Voc used for configuration must be considered with temperature coefficient effected by environment at each install location. **For operation of charge controller at ambient temperature ≤ 25˚C. The peak PV power must be derated 15% when charge controller operates at ambient temperature over than 25˚C. Continuous product development is our commitment. In that manner, the above specifications may be changed without prior notice.

Authorized Distributor

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P.LEN.BRO.CCL.050 Rev.12.00/2015

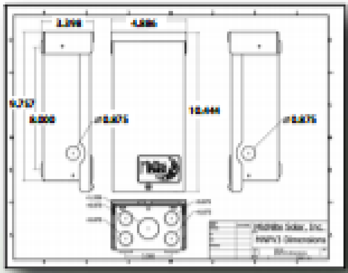
ETSEIB

MidNite MNPV6-250 DATASHEET

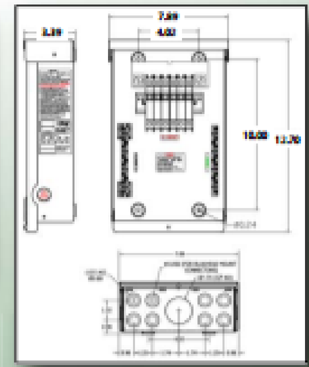
MidNite Solar's

PV Combiners

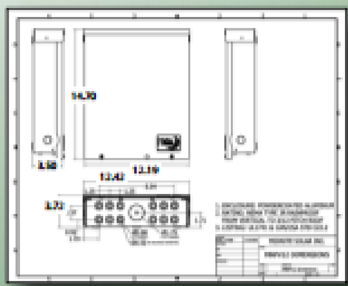
MidNite Solar offers a range of PV Combiners from our MNPV3 to the MNPV12v. This range of combiners accommodates PV systems as small as a two string off grid cabin up to 12 strings for a 50KW commercial grid tie inverter.



MNPV2-MC4 and MNPV3



MNPV4-MC4, MNPV6 and MNPV6-250



MNPV8-MC4, MNPV12 and MNPV12-250

Intertek ETL Listed C US

MidNite Solar PV Combiner Specifications

	MNPV2-MC4 and MNPV3	MNPV4-MC4, MNPV6 and MNPV6-250	MNPV8-MC4, MNPV12 and MNPV12-250
Enclosure rating	Outdoor Rainproof NEMA 3R	Outdoor Rainproof NEMA 3R	Outdoor Rainproof NEMA 3R
Enclosure material	Powder coated aluminum with stainless hardware	Powder coated aluminum with stainless hardware	Powder coated aluminum with stainless hardware
Mounting options and angle	Vertical wall mount, pole mount or sloped roof mount to 14 degrees incline (3 in 12 roof pitch)	Vertical wall mount, pole mount or sloped roof mount to 14 degrees incline (3 in 12 roof pitch)	Vertical wall mount, pole mount or sloped roof mount to 14 degrees incline (3 in 12 roof pitch)
Number of PV strings	MNPV2-MC4 two strings, MNPV3 two strings with fuses, three strings with 150 volt breakers	MNPV4-MC4 four strings, MNPV6 four strings with fuses, six strings with 150 volt breakers, MNPV6-250 three strings with 300 volt breakers	MNPV8-MC4 four strings MNPV12 eight strings with fuses and twelve strings with 150 volt breakers MNPV12-250 six strings with 300 volt breakers
Maximum number of output circuits	1 for all	MNPV4-MC4 and MNPV6 is two, MNPV6-250 is one	2 for all
Wire range for string input	MNPV2-MC4 NA uses MC4 connectors, MNPV3 14-6 AWG	MNPV4-MC4 NA uses MC4 connectors MNPV6 and MNPV6-250 14-6 AWG	MNPV8-MC4 NA uses MC4 connectors MNPV12 and MNPV12-250 14-6 AWG
Maximum OCPD rating	30 amp with fuses and 63 amps with 150 volt breakers	30 amp with fuses, 63 amps with 150 volt breakers and 50 amps with 300 volt breakers	30 amp with fuses, 63 amps with 150 volt breakers and 50 amps with 300 volt breakers
Maximum output amps	60 amps for all	80 amps for fused, 120 amp for breakers	200 Amps with Fuses and 150 volt breakers, 168 amps with 300 volt breakers
Output wire range	14 to 1/0 AWG	14 to 1/0 AWG	14 to 1/0 AWG
Lug temperature rating	90 deg C	90 deg C	90 deg C
Deadfront	Custom molded plastic deadfront	Custom molded plastic deadfront	Custom molded plastic deadfront
Lockable	Yes	Yes	Yes
Rating	UL1741	UL1741	UL1741

www.midnitesolar.com
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