SCHOOL OF SCIENCE AND ENGINEERING

Smart Home Energy Management System

Monitoring and Control of Appliances Using an Arduino Based Network in the context of a Micro-grid

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A. Khalil
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Abstract

The United States, European Union, China and Russia, which are among the regions of the wider world and the most populated, consume over 61% of global electricity. Between 2001 and 2012, consumption of some developing countries has increased significantly: it has been multiplied by 3.3 for China, India by 2.2 and 1.6 for Brazil [1]. The energy used is most of the times produced from nonrenewable sources that may be causing the global warming that the planet is presently experiencing. People are not aware of threats of energy wastage and are increasingly looking for more comfort by having many devices in their home that are turned on the whole day, and sometimes leaving their houses and leaving a bulb on, heaters, or TV’s, etc. In this work, we suggest the design and implementation of a home energy management system to enable households to have continuous data on their energy consumption to save energy. The solution already exists in the market, but the purpose of project is to design and implement a home energy management system that provides users with detailed information about their energy consumptions and permit sensing, control, and smart algorithms with the use of renewable energy as a source of electricity at the residential level within the Moroccan context in a micro-grid. Renewable energy is increasingly at the heart of conversations and many economic and political debates in Morocco. With the rising number of photovoltaic installations worldwide, arise to a greater extent the question of the attitude of this technology for integration into the network of distribution and transmission. The potential studies developed so far in the field of solar energy in Morocco determine, on the basis of the surface, the theoretical and technical national potential, which is huge because of the intensity of solar radiation and availability large spaces. This project emphasizes the importance of the use of renewables in a micro-grid and also on implementing two Smart Plugs using an Arduino-based network.
1. Introduction

1.1 Context

The development in the renewable energy field and the increasing number of new uses of electricity generated a need to modernize the electrical system. Some existing uses have grown considerably like heaters, air conditioners and other uses like hybrid electrical vehicles and heat pumps are developing and increasing the power consumption. These changes are forcing the control of power systems because of electricity consumption variations: electricity is more consumed in winter than in summer which makes it subject to daily peaks and hollows. And also due to the fact that power generation means are increasingly varying because of alternating renewable sources. The last reason is the development of distributed generation leads to a significant increase in the production sites and also to inject energy on distribution networks designed to deliver it, not to collect it.

Making the electrical network smart is therefore largely instrumenting them to make them able to communicate. Currently the transportation network is already instrumented particularly for reasons related to security of supply. However, distribution networks are poorly endowed with communication technologies, due to the large number of works (stations, lines, etc.) and consumers connected to these networks. The challenge of smart grids thus lies mainly in the distribution networks. The following table (table 1) represents the advantages of the smart grid comparing to the existing electricity grids. Unlike the current grid, the smart grid has better communication that is on both ways, the power system management according to the consumption and there is not only a consumer but the consumer that is in the same time an actor.
Table 1: Comparison between the characteristics of the current electricity grid and the smart grid [2]

<table>
<thead>
<tr>
<th>Characteristics of the current electricity grids</th>
<th>Characteristics of smart grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog</td>
<td>Digital</td>
</tr>
<tr>
<td>Unidirectional</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>Centralized production</td>
<td>Distributed generation</td>
</tr>
<tr>
<td>Communicating on a part of the networks</td>
<td>Communicating on all networks</td>
</tr>
<tr>
<td>The balance of power system management by supply / Production</td>
<td>The balance of power system management by demand / consumption</td>
</tr>
<tr>
<td>Consumer</td>
<td>Consum'actor</td>
</tr>
</tbody>
</table>

1.2 Previous work

Many projects have been done previously by Capstone Students and laid the ground for this project. The first one was done by two Capstone students “Abdelkarim Adyel” and “Soukaina Mouatadid” on “Load Profiling in the Moroccan Residential Sector”. They tackled the different load profiling types and methods, smart houses, and methodologies of energy audit. Another point of their project was the approximation of Moroccan consumption profiles which was achieved by using surveys. Then, with the collected data from surveys, simulations were conducted and energy efficiency recommendations were formulated. Another interesting project on the implementation of a “Home Energy Management Android Application” by capstone students “Imane L’hadi” and “Sarah Lahtani”. The purpose of this application was the monitoring and management of household appliances and renewable sources of energy in terms of consumption and generation. This “Home Energy Management Android Application” was updated by research student “Mohammed Bakr Sikal” as new features were added to meet the SHEMS requirements. In parallel to this work, “Zineb Chelh” another capstone student performed research about “Challenges of implementing the Smart Grid in developing
countries” with an emphasis on the challenges facing the transition towards a smart grid in Morocco.

The last projects were done by two other capstone students “Soukaina Brangui” and “Ismail El Hamzaoui”. The purpose of this project was the implementation of an Arduino based Smart Home Energy Management System.

The expected Results of this project is to design an efficient Smart Home Energy Management system that make use of Renewable Energy sources. This project analyses the possibility of implementing a SHEMS in a micro-grid context that makes use of Renewable Energy in Morocco in the residential sector.

### 1.3 Problem Statement

Given the growing energy demand and declining fossil energy supply, the design of SHEMS will help increase the use of renewable energies and decrease household’s dependency on the grid by providing automatic energy saving measures and better manage the use of Renewable Energy sources within the household. The overall project will have as intent, to design a SHEMS. The system will be able to control and monitor the different appliances in a house. The problem tackled in this report is the monitoring and control of the different appliances in a house. There will be also an analysis of the possibility of the use of renewable energy in Morocco in a Micro-Grid through a case study.

### 1.4 Steeple analysis

The steeple analysis is method or tool used to help taking decision by taking into consideration seven macro-environmental factors which initials form the name of the method used: Societal, Technology, Environment, Ethics, Political, Legal, and Economic. The macro-environment includes the factors that influence the position of the company in its market by changing its offer and demand, but in an exogenous manner. These are factors over which we don’t have any effect and we cannot handle, but must anticipate because they are sources of opportunities and in the same time threats. This method is going to be used to analyze the macro-environmental factors of this research paper:
<table>
<thead>
<tr>
<th>Category</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Societal</strong></td>
<td><em>World's population is increasing which gave birth to changes in social behavior. People are looking for more comfort using new devices extensively which creates an increase in energy demand.</em></td>
</tr>
</tbody>
</table>
| **Technology** | *Technology is developing and facilitating the implementation of many systems and is helping in the development of many fields. The advancement of technology is helping many projects to emerge and one of them in Home Energy Management System.*  
*Technology advancement can also be a threat for the implementation of the smart home energy management system (HEMS) because technology is accessible by anyone which implies more competitors.* |
| **Environment** | *The smart home energy management system is environmentally friendly since it encourages the use of renewable energies to save the environment.*  
*The use of renewable energies in the SHEMS can be a threat because there are some issues that are not yet solved in this field since it is still a new field.* |
| **Ethics** | *Privacy is a very important concern for the implementation of the SHEMS. The data collected must be secure.* |
| **Political** | *Some countries that do not produce oil will be more independent from other producing countries.* |
| **Legal** | *There are many laws about renewable energies. In the Moroccan context, there is a law N°16-09 for the implementation of the policy of energy efficiency and renewable energy. And due to the law 13-09 that is related to renewable energies a new law is discussed about low voltage integration.* |
| **Economic** | *The implementation of the SHEMS has many effects on the economy because of lowering the cost of energy.* |
1. Literature Review

1.1 SMART GRID: History and Drivers

1.1.1 Drivers for Smart Grid

Between 2010 and 2030, the economic growth should lead to a global energy demand twice as large as the one we know today. At the same time, global carbon dioxide emissions are expected to increase at a rate even greater than the energy demand. The largest source of CO2 is the generation of electrical energy which makes important climate change. To solve this problem many modifications should be made regarding the existing electrical system.

Electricity is the most adaptable and extensively used form of energy with a continuous growing global demand. Generation of electrical energy is currently the largest single source of carbon dioxide emissions, making a significant contribution to climate change. To diminish the implications of climate change, the current electrical system needs to undergo significant adjustments.

The electrical power system distributes electrical energy to industry, commercial and residential users, to meet the ever-growing demand. Most of today's generation capacity relies on fossil fuels and contributes significantly to the increase of carbon dioxide in the world's atmosphere, with negative consequences for the climate and society in general[3].

Renewable energy sources, such as solar power, wind power and fuel cell etc., should be used to meet the increasing energy. There are many challenges caused by integrating renewable energy sources into grid that can be solved by redesigning the conventional power system infrastructure and architecture. The conventional power system should be more reliable, environmental friendly and intelligent comparing to the existing systems. [4]

To satisfy both the increasing demand for power and the need to reduce carbon dioxide emissions, we need an electric system that can handle these challenges in a sustainable, reliable and economic way. To realize these capabilities, a new concept has emerged; the smart grid [5].

As a consequence the main drivers for the smart grid:

- **Reliability**: Providing energy that has high-quality whenever it is needed
- **Capacity**: achieving the increasing global demand of electricity
- **Efficiency**: making power generation more efficient and reduce losses from distribution, transmission and consumption.
- **Sustainability**: By using and integrating renewable power generation.

### 1.1.2 Smart Grid Definition

The Smart Grid is a smart power grid that uses computer technology to optimize production, distribution and consumption of electricity in order to promote the supply and demand between suppliers and consumers of electricity. By storing an optimal amount of information about network status, smart Grids help maintain the balance between production flows, distribution and power consumption.

There are new power system challenges that paved the way to the concept of smart grid. Smart grid is composed of communications, sensors, control and computational ability in order to improve the general functionality of the power system [6]. The purpose of smart grid initiatives is to enhance maintenance, operations and planning using new technologies to have a better management of energy consumption and costs.

United States Department of Energy has defined the functions required for smart grids in [7]: the ability to heal itself; to motivate consumers to actively participate in operations of the grid, to resist attack, to provide higher power quality, to accommodate all generation and storage options, to enable electricity markets to flourish, to manage more efficiently the assets and costs. In other terms, the smart grid can be defined as “the next generation, distribution and consumption”. [8]

### 1.1.3 Smart Grid in History

The Smart Grid concept is still a new and young idea, the term was first introduced in the late 1990s and the first practical large-scale example established in the early 2000s[9]. Most electric power systems rely on older ideas and old infrastructure, therefore the grid is not well prepared for challenges of the 21st century.

Italy was accredited the implementation of the first Smart Grid by the country’s largest energy company called Enel S.p.A., starting in 2000. From that time until now, the company has installed more than 30 million smart meters across the country [9].
The US began setting up its Smart Grid in 2003. It has now a total number of 200,000 devices online and another 300,000 that is expected to join the network. Austin was followed by Boulder, Colorado[9]. Boulder represents the home of the first wholly working Smart Grid-enabled city in the US, it has a network containing more than 23,000 smart meters.

Since then, many other countries and parts of the US were affected and have taken early steps toward the implementation of the Smart Grid and moving from one-way systems to fully bi-directional systems[9].

1.2 Renewable Energies Integration in a micro-grid

1.2.1 Photovoltaics Overview and technologies

1.2.1.1 Photovoltaics definition

Throughout this project we’ll be using Photovoltaics as a form of renewable energy source for the micro-grid. Photovoltaic solar energy comes from the conversion of sunlight into electricity using semiconducting materials, like silicon or covered with a thin metallic layer, that exhibit the photovoltaic effect. These photosensitive materials have the property of releasing their electrons under the influence of external energy. This is the photovoltaic effect. Energy is supplied by the photons (light components) which face the electrons and release them, inducing an electric current. This DC Micro-power calculated in watt peak (Wp) may be converted into alternating current using an inverter. [10]

The electricity produced is available either as direct electricity or stored in batteries (decentralized electricity) or electricity fed into the grid.

A photovoltaic generator is composed of photovoltaic modules themselves compounds of photovoltaic cells connected together.

1.2.1.2 Photovoltaic technologies

Different technologies are used to produce solar panels; the most common are those that use the following photovoltaic materials or technologies[11]:

- The crystalline silicon
Solar panels based on crystalline silicon are the oldest. They are split themselves in two variants: monocrystalline and polycrystalline. Monocrystalline silicon produced by cutting wafers from a high-purity single crystal block and polycrystalline silicon made by sawing a cast block of silicon first into bars and then into wafers. These two variants are now very close both in terms of efficiency in terms of cost. The efficiency of a photovoltaic panel is the amount of solar energy converted into electricity by the panel consumable, compared to the captured energy. The average yield of a crystalline panel market is 14.5%.

- The amorphous Thin film Cells silicon

The mechanical flexibility of amorphous silicon allows it to be used mainly in type complex "Solar membrane" or "solar plate". The average efficiency of solar panels amorphous silicon is 6 to 8%.

![Diagram of solar cell using amorphous silicon](image)

Figure1: A solar cell using amorphous silicon [12]

As shown in Figure 1, they are using a triple layer system that is optimized to capture light from the full solar spectrum, and it has a thickness of just 1 micron, or about 1/300th the size of mono-crystalline silicon solar cell.[12]

The main characteristic of thin film photovoltaic modules is that: they produce power at low cost per watt. They are ideal for large scale solar farms, as well as Building Integrated Photovoltaic applications (BIPV). They benefit from generating consistent power, not only at elevated temperatures, but also on cloudy, overcast days and at low sun angles.[13]
Figure 2: A solar cell using thin film technology

As shown in Figure 2 and stated in [13], thin film photovoltaics consist of a stack of extremely thin photosensitive layers sandwiched between a top Transparent Conductive Oxide (TCO) coating and a back contact. The photovoltaic layers are laminated between a TCO glasses.

1.2.2 Components of Photovoltaics

The main components of a photovoltaic system:

- The photovoltaic solar panel: it produces the required amount of electricity.
- Solar charge controller and solar load limiter: protects the battery against overload and deep discharge.
- Solar Battery: She stock the energy produced by the photovoltaic solar panel.
- Accessories:
  - Cables: They ensure the connection of components.
  - Converter: it adjusts the DC voltage from the solar battery to the receiver supply voltage if it is high or low.
  - Inverter: converts the direct current (DC) to alternating current (AC). A solar inverter converts the electricity from your solar panels (DC, or direct
current) into power that can be used by the plugs in your house for your TV, computer, and other wired products (AC, or alternating current). Panels can’t create AC power by themselves; they need the helping hand of a solar inverter [14]

1.3 HOME ENERGY MANAGEMENT SYSTEM

1.3.1 What is a Home Energy Management System

Energy consumption in the residential sector represents an important part of the total electricity demand. In this context, a proper prediction of energy demand in housing sector is very important. Energy use in home accounts for significant part of total energy consumption both in developing and western world. Residential buildings currently account for large part of the total energy demand [15].

HEM system is an important part of the smart grid and has many benefits such as:

- Reduce the electricity bill
- Reduction of demand in peak hours
- Meeting the demand side requirements

One of the HEMS objectives is to decrease the peak demand of households by controlling power intensive loads and in the same time take into account the comfort and priority of the customer. Home energy management system that is based on Zigbee communication allows the households to regulate power of the smart devices after receiving a signal from the service provider. “There are two energy consumption peaks during the day: in the morning, between 8 and 10 AM, and in the night, between 6 and 10 PM. The role of cost control is to change the load curve shape in such a way that energy consumption peak decreases, even though the total consumption for the specific household is the same” [16].

Energy prediction for appliances in homes has a great influence in the functioning of a home energy management system. This system is able to determine the best energy assignment plan and a good compromise between energy production and energy consumption. [16]

The Home Energy Management System is mainly composed of Smart plugs, Gateway, Web server, Database and a user devise.
1.3.2 Home Energy Management Requirements

Figure 3. Example of an Energy Management System in a smart grid [17]

Figure 3 explains the key parts of the Home Energy Management System and the main requirements for a HEMS that will help the monitoring and control of energy. The requirements as stated in [18] are:

- **Monitoring**: provide a frequent energy consumption information by the system to the consumer.
- **Disaggregation**: the system has to provide disaggregated data about each appliance. From the information given by the system, the impact of specific appliances and the impact of long term changes can be clearly highlighted.
- **Availability and accessibility**: Information should be provided at all times with an easy to use interface.
- **Information integration**: in addition to providing disaggregated data. The system should provide other kinds of information that are related to different appliances like: temperature , humidity …
- **Affordability**: The system should be easy to install and have minimal consumption.
• **Control:** The consumer should be able to control manually its devices.

• **Cyber-Security and privacy:** The system must ensure that consumer’s data are secure and private.

• **Intelligence and Analytics:** the system have to be able to take some intelligent decisions taking into consideration the data available.

1.3.3 Home Energy Management Challenges

The HEMS was not fully implemented because of many challenges that this technology is facing. In paper [19] many challenges are stated which are summarized below:

• **Cost:** The cost of HEMS is expensive in terms of device prices and the installation costs. People are not ready to invest in systems whose profits hardly meet their investment. [20].

• **No standards for HEMS:** There is no specific way for the design and implementation of the system since each seller offer its own system with a unique design and control strategies.

• **Low consumer awareness:** Consumers are unaware about the functionality of the Home Energy Management System. Sometimes costumers are confused between several HEMS solutions proposed in the market [21].

• **HEMS aggregation:** It is still unclear to integrate the HEMS in the bigger picture of the smart grid. Research shows that energy management for individual households are not efficient. Aggregation presents better optimization and utilization of resources.

• **Choice of Information and Communication Technology (ICT):** ICT is an enabling technology to the successful implementation of HEMS. Some residential customers are worried about the health effects of the penetration of wireless signals that are part of their HEMS.

• **Designing system intelligence:** It is difficult to design a system that meets different levels of consumers’ knowledge about HEMS.
2. GENERAL OVERVIEW OF PHOTOVOLTAICS

Solar photovoltaic cells directly convert solar energy into electrical energy. Over 90% of the photovoltaic modules are based on crystalline silicon. The remainder, just 10%, consists of thin-film modules and other new technologies.

The photovoltaic market has grown by an average of 50% over the last decade. This development has been systematically underestimated for a long time. According to an article in the publication PHOTON over 40 scientific studies, 38 have underestimated the production capacity as well as the dynamics of the market for PV, or underestimated the forecast. Photovoltaics is one of the technologies on which a legislative framework based on a promotional policy has a strong influence. With a rapidly growing market, photovoltaic technologies have rapidly diversified. The peculiarity of the photovoltaics is – in parallel to the physical mechanism of transforming sun light to direct current – its prodigious modularity: it can be used by all the orders of magnitude, from Milliwatt in form of cell to hundreds of MW installations.

In 2010, the volume of the photovoltaic installation worldwide increased, according to the market research company: IMS Research, to 17.5 GW with an increase of 130% compared to the previous year. In 2011, a capacity of 20.5 GW installation was planned, which create an increase in the total installed capacity worldwide to 58 GW until the end of 2011.

2.1. Mono and polycrystalline technologies

Silicon is since decades the essential component of solar cells. Currently produced solar cells have as base materials the mono- (50%) and poly-crystalline (50%). Purity requirements for silicon are very high. In 1 billion atoms of silicon atoms, there are only one impurity atom.

Its manufacture is similar to that of electronic chips. The mono-crystalline silicon cells are made according to the Czochralski method, with extraction of a massif "slug" from a bath of molten silicon, then cut into thin plates (wafers). The Poly-crystalline silicon is melted and slowly cooled. This process allows the formation of the typical structure of crystals; this simplified process reduces manufacturing costs. The disadvantage of poly-crystalline silicon is the presentation of more contaminations and defects such as grain boundaries and mutations, affecting the rate of efficiency. To keep the yield energy efficiency high, getters and specific passivation processes must be carried out.
The silicon cells had in 1990 a thickness of 400 microns, while today they generally have a thickness of 200 microns. The Fraunhofer Institute developed a solar cell with a thickness of 40 microns only an efficiency of 20%. The energy efficiency ratio rose from 10% at baseline to 14 to 16% on average for the poly-crystalline cells and 17-20% for monocrystalline cells.

The silicon demand has increased dramatically. For a long time, solar cells were produced from residues from the production of microchips. Starting with annual production quantities from 1 to 5 MWp in the 1990s, the quantities produced augmented to several hundred of MWp. After a phase of scarcity in the years that followed 2003, silicon production capacity was increased globally and in the same time technological innovations have also been developed: in parallel to the development of a silicon with a specific "solar grade" (which has a lower degree of purity), the development of thinner cells was encouraged and thin-film technologies have been booming.

2.2. Thin film Technologies

The category of thin film technology includes different types of materials. They have the advantage of being 100 times finer than the standard silicon cell. Technologies in most known thin film is based on amorphous silicon, copper - indium di-selenide (CIS) and cadmium telluride (SCTD).

Amorphous silicon (a-Si) is composed of unordered silicon atoms that are sprayed on a substrate. Its high absorption capacity allows to obtain particularly thin layer thicknesses of 3 microns to 20 microns. Moreover, it has the drawback of having a commercial efficiency rate of 6 to 8% only. To increase this rate, several layers are combined, using silicon-germanium alloys (a-SiGe) or micro morphs layer (μc-Si).

The advantages of thin film solar cells are:

- A low sensitivity to temperature and opacity.
- The possibility of applying them to flexible materials such as steel plates or sheets of plastic.
- Their good sensitivity to diffuse or weak light.

Compound Semiconductors II-VI-cadmium telluride (CdTe) and copper indium di-selenide (CIS, CuInSe2), now mostly used for thin-film technologies, have already achieved significant reductions in price. In December 2010, prices of modules ranged from 1.22 to 1.38 € / Wp.
The EER in commerce are between 8 and 12%. The maximum value for a laboratory CdTe cell is 16.5%. Due to its toxicity, many CIS cell manufacturers replace di-selenide by disulfide or or add gallium (CIGS). For CIGS thin film modules, an efficiency rate of 15.1% was published by Avancis the 31th of January 2011. The spectrum of the cell configuration is the subject of intensive research worldwide; can be estimated approximately until 2020 how "technological leaps" - including in terms of production optimization - will continue to drive down prices of PV, but this alleged evolution does not exclude completely some totally innovative concepts.

### 2.3. Types of Solar Systems

The basic unit of a photovoltaic system is the solar module which are electrically connected to a plurality of solar cells, also connected together. Several modules are connected to a solar generator.

There is a difference of principle isolated installations connected to the network. Isolated installations store the current in batteries (accumulators), while network-connected installations inject electricity generated in a distribution network.

#### 2.3.1. Off grid/Isolated Solar System

Off grid (or Stand-alone) PV systems are designed in a way to be independent of the electric grid. Since PV panels cannot store energy and is able to generate electricity only during daylight hours, for a continuous flow of power they need to generate excess of the energy that has to be stored somewhere. Generally, this excess of energy is stored in the batteries.

If the off grid home has no other power source, the design of both the PV and the battery have to be meaningfully oversized to account for possibly 4-5 days of inclement weather. To reduce the size of the battery and the panels, off-grid homes uses solar systems that are often supplemented with wind turbines that are able to produce electricity during cloudy periods and at night. The other auxiliary source that is often used are which simplifies the isolated system's sizing. Another reason batteries should be used off-grid is to operate the PV cells near their maximum power point.
Figure 4. Schematic representation of an off-grid solar system [22]

2.3.2. PV Installation connected to the grid

In the case of a photovoltaic installation connected to the network, the direct current produced by the solar cells is converted by an AC inverter which is injected into the customer's internal network or the electrical distribution network through one (or two) counter(s).

There are two coupling variants, which have economic consequences for the investor (whether an individual, a company or a project developer):

1. According to a system of "feed-in tariff" (with premium rates set by the state), as presented in more than 40 countries, all of the electricity generated by the PV system is injected into the network. The amount injected is measured by an "injection counter" to determine the amount of electricity to remunerate. The producer gets paid by the operator of the electricity grid at a premium rate, and funds through this investment. The amount consumed by the consumer is reviewed by another "supply meter" (Figure below) and the customer pays its consumption according to the usual tariff conditions.
2. According to a net metering system, the installation is connected to the internal network and consumer electricity primarily covers his personal needs.

Figure 5. Schematic Representation of a PV installation with a feed-in tariff system.[22]

Figure 6. Schematic Representation of a PV installation with net-metering system. [22]
If the production of photovoltaic system exceeds the consumer's needs, the excess is fed into the grid; if lower, the consumer collects electricity in the network. For the realization of this system, a simple counter is sufficient, but it must be able to measure the flow of electricity in both directions.

![Schematic Representation (a) and (b) of an installation connected to the grid with a net-metering system](image)

(a) The electricity generated is used to cover the personal consumption.  
(b) In the absence of own need, the electricity is fed into the grid.

**Figure 7.** Schematic Representation (a) and (b) of an installation connected to the grid with a net-metering system[22].

### 2.4. Detailed Photovoltaic Components

To better understand the operation of the system, it is necessary to know the technological structure. A photovoltaic is composed of four main parts:

**a- The solar panel**

The role of the solar panel is to deliver energy to the load and to the battery. It is composed of: the photovoltaic module and the cell.

*The photovoltaic module*

A solar panel consists of an assembly in series of individual cells encapsulated in a single carrier. The number of cells determines the rated voltage while the cell size imposes the peak current.

Individual cells constituting the module, being interconnected in series, the resulting voltages and currents will follow the laws of DC generators. The current output and the power are consequently proportional to the surface of the module.

*The cell*

A cell consists of a stack of layers:
- Protective glass
- Antireflection coating
- Conductive mesh (cathode)
- Silicon doped N (negative)
- N / P junction
- Silicon doped P (positive)
- Metal support (anode)

The qualitative operation of a cell is quite simple: the photons (light particles) hit the cell, they transfer their energy to the electrons of silicon. The silicon is treated (doped) so that all the electrons are moving in the same direction, toward the top of the metal grid, thus creating a DC current whose intensity is a function of the insolation.

The characteristics defined by the manufacturers are obtained under standard test conditions (STC) as follows:

- **Junction temperature**: 25 °C
- **Irradiation or illumination E**: 1000 W/m² (100 mW/cm²)

This corresponds approximately to the power of sunlight at noon on a clear day and on a surface of 1 m² perpendicular to the direction of sunlight.

*Air mass AM* is when the sun is at its zenith. The "air mass" is the atmospheric layer that radiation must pass.

**b- The Battery**

*The role of Batteries*

The battery is used to store excess electrical energy produced by the one or more solar panels. This energy is stored in chemical form. At night it is the battery that provides energy. The storage is sized for a period of several days without sun, allowing for a wide range of emergency and taking into account the battery lifetime phenomena and loss of cycling-related capacity (charge and discharge).

*The Capacity of the battery*

The capacity is the amount of electricity that the battery can deliver for a given period, under a discharge rate and a given ambient temperature. Capacity decreases at low temperature, high discharge rate and aging.
This capacity is expressed in Ah (ampere hours). The international standard defines as follows:

- **Rated capacity unaccumulator Lead**: The capacity C20 is the value obtained in ampere hours during continuous discharge and uninterrupted for 20 hours to a discharge end voltage of 1.75 V per cell at 20 °C. The current rating is 1/20 of the capacity in ampere hours.

  - **Example Calculation of the current rating:**

    Battery capacity 12 Ah C20 =

    Current = capacity / discharge time

    \[ I = \frac{12}{20} = 0.6 \text{ A for 20 hours} \]

  - **Example of calculation of capacity**

    \[ V = 48 \text{ V} \]

    \[ P = 1200 \text{ W} \]

    Autonomy: 4 hours

    \[ U_{\text{max}} = 48 \text{ V} \]

    \[ U_{\text{min}} = 40 \text{ V} \]

    **Current**: \[ I = \frac{1200}{48} = 25 \text{ A} \]

    **Minimum of voltage for an element**: \[ 40/24 = 1.85 \text{ V} \]

    **From the discharge curve**: \[ 1.85 \text{ V } 0.2 \text{ C20 (C20 } 0.2 = 25 \text{ A) } 12. \]

    The capacity must be such that:

    \[ \text{C20} = \frac{25}{0.2} = 125 \text{ Ah} \]

  - **The controller**

    **The role of the controller**

    The controller has as a function the management of the charging and discharging of the battery. It enables optimal energy transfer between the solar generator and the battery while minimizing the depth of discharge and protecting the battery from overcharging, which cause premature aging.
The structure of the controller

The controller has a switching element - relay, bipolar transistor, MOSFET transistor, thyristor - placed between the solar panel and battery. It is controlled by a logic based on the control of the voltage of the battery, and can easily switch high currents without internal energy dissipation.

The characteristics of the controller

The controller has usually several technical characteristics:

- Protection against polarity reversing (solar panel or battery)
- Diode integrated check valve (prevents the return of power to the generator)
- Voltage alarm function in case of low battery voltage
- Viewing the charge states by LEDs
- Protection against lightning, short circuit
- Display of the battery voltage and current of charging and discharging
- The choice is generally carried out according to the voltage (12 V, 24 V) and the maximum power from solar panels.

The role of the inverter

The inverter is a DC-AC converter. For the Off grid system, the inverter provides power receivers operating on alternating current. We currently use inverters with an alternative quasi-sinusoidal output signal.

For systems connected to the grid, you can use an inverter to transmit energy to the network. In this case, use a sine wave inverter, which costs 4 to 5 times more expensive than a quasi-sine wave inverter. The difference is that the signal is pure (sinusoidal) and that to reach this level, filters had to be used.
2.5 Sizing an off-grid solar power system

**Step 1**

Calculate the daily energy consumed by the source(s) in watt-hours.

\[ E_{\text{Daily Consumed}} = \text{Source Wattage} \times \text{Daily Operating Hours} \]

E unit is: watt-hours/day

**Step 2**

Calculate the electric energy that the PV panels need to produce each day.

Assume the battery capacity of the system is large enough to allow necessary charging and discharging for powering the source(s).

\[ E_{\text{PV Produced}} = \frac{E_{\text{Daily Consumed}}}{(\text{Electronics Efficiency} \times \text{Battery Charge/Discharge Efficiency})} \]

**Step 3**

Calculate the amount of solar radiation that the PV panels need to collect each day.

\[ E_{\text{Solar Radiation Needed}} = \frac{E_{\text{PV Produced}}}{(\text{PV panel conversion efficiency})} \]

**Step 4**

Find the average daily solar radiation at the location in which this appliances will be used

**Step 5**

Calculate the size of the PV panels needed.

If the PV panel is in a horizontal position:

\[ \text{Size of PV Panels} = \frac{E_{\text{Solar Radiation Needed}}}{\text{Daily Solar Radiation}} \]

If the PV panel is tilted with an angle of latitude plus 15 degrees (facing south):

\[ \text{Size of PV Panels} = \frac{E_{\text{Solar Radiation Needed}}}{\text{Daily Solar Radiation}} \]
3. Case Study: Sizing Pv Panels for a house located in Ifrane.

The purpose of this case study is to design an off-grid solar power system that fits the conditions of a chosen house with defined appliances. To do so, we’ll start with sizing the PV needed, then sizing the battery. The last step of this case study will be an analysis of the return on investment of using a Photovoltaic system in a SHEMS. The home chosen in this case study is composed of: a Fridge, an Air conditioner, an LCD TV, a Computer, a Waching machine, an Iron, a Vacuum cleaner, a Hair dryer, eight Lamps (Energy saving lamps), a Cooker, an Electric oven, a Microwave, a Home Boiler. In this case study, I overestimated the overall consumption to see the worst case scenario of the return on investment.

The choice of an autonomous solar kit primarily depends on the forecast consumption appliances. The logic of calculation is to combine the power ratings (W) of your electrical devices and multiply by the number of hours (h) use per day (Wh / day). Then refer to the solar output tables to determine the necessary number of solar panels. The following table (Table 2) calculates the estimated total average consumption for the house in kwh/day.

<p>| Table2. Total electricity consumption in a home with specific appliances |</p>
<table>
<thead>
<tr>
<th>Appliances</th>
<th>N°of items</th>
<th>Power (W)</th>
<th>Period of utilisation</th>
<th>AverageFrequency</th>
<th>Average annual consumption(kwh)</th>
<th>Average annual consumption for all items(kwh)</th>
<th>Estimated average consumption(wh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fridge</td>
<td>1</td>
<td>up to 200</td>
<td>365 days</td>
<td>Continuous</td>
<td>201</td>
<td>201</td>
<td>550</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>1</td>
<td>up to 4000</td>
<td>60 days</td>
<td>5h/day</td>
<td>960</td>
<td>960</td>
<td>16000</td>
</tr>
<tr>
<td>LCD TV</td>
<td>1</td>
<td>up to 250</td>
<td>335 days</td>
<td>4h/day</td>
<td>241</td>
<td>241</td>
<td>720</td>
</tr>
<tr>
<td>Computer</td>
<td>1</td>
<td>up to 80</td>
<td>240 days</td>
<td>4h/day</td>
<td>72</td>
<td>72</td>
<td>300</td>
</tr>
<tr>
<td>Waching machine</td>
<td>1</td>
<td>up to 2200</td>
<td>48 weeks</td>
<td>4cycles /week</td>
<td>173</td>
<td>173</td>
<td>900</td>
</tr>
<tr>
<td>Iron</td>
<td>1</td>
<td>up to 1100</td>
<td>48 weeks</td>
<td>5h/week</td>
<td>260</td>
<td>260</td>
<td>1100</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>1</td>
<td>up to 800</td>
<td>48 weeks</td>
<td>2h/week</td>
<td>70</td>
<td>70</td>
<td>800</td>
</tr>
<tr>
<td>Hair dryer</td>
<td>1</td>
<td>up to 600</td>
<td>48 weeks</td>
<td>30min/jour</td>
<td>11</td>
<td>11</td>
<td>300</td>
</tr>
<tr>
<td>Lamp( Energy saving lamp)</td>
<td>8</td>
<td>up to 25</td>
<td>335 days</td>
<td>5h/day</td>
<td>34</td>
<td>272</td>
<td>800</td>
</tr>
<tr>
<td>Cooker</td>
<td>1</td>
<td>up to 10000</td>
<td>335 days</td>
<td>2h/day</td>
<td>3200</td>
<td>3200</td>
<td>9500</td>
</tr>
<tr>
<td>Electric oven</td>
<td>1</td>
<td>up to 2500</td>
<td>48 weeks</td>
<td>1,5h/semaine</td>
<td>162</td>
<td>162</td>
<td>2500</td>
</tr>
<tr>
<td>Microwave</td>
<td>1</td>
<td>up to 1500</td>
<td>48 weeks</td>
<td>1,5h/semaine</td>
<td>90</td>
<td>90</td>
<td>750</td>
</tr>
<tr>
<td>Home Boiler</td>
<td>1</td>
<td>up to 2500</td>
<td>335 days</td>
<td>80l /day</td>
<td>1554</td>
<td>1554</td>
<td>4638,80597</td>
</tr>
</tbody>
</table>

**Total in Wh/day :** 38858,80597

**Total in KWh/day :** 38,85880597
Total consumption per day (from Table 2) (Wh/day)  |  38858,80597
---|---
Irradiation optimal (Wh/m²/day)*  |  5630
Efficiency of the off-grid system  |  0.66
Power (Kwp) **  |  10,45772269

**Table 3. Power needed to cover total consumption**

*The irradiation of Ifrane is available in the following website: [http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa](http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa) after pressing the button “calculate” in the monthly radiation tab. We get the result in Appendix A.

Hopty: Irradiation on optimally inclined plane (year): 5630

**To calculate the Power needed:**

\[
\text{Power in Kwp} = \frac{E \left(\text{in kwh/day}\right) \times 1 \text{wh/m}^2}{0.66 \times \text{Irradiation(wh/m}^2/\text{day})}
\]

\[
\text{Power} = 10.45 \text{ kWp} = 10450 \text{ Wp}
\]

Now, we need to calculate the number of panels needed. I choose to use the panel SOLON Black 220/16 with monocrystalline technology (See appendix B). I choose this technology because it is the most used in the market and even though it is slightly more expensive than polycrystalline but it is more efficient.

According to appendix B, the maximum power of the panel is: 250Wp. Therefore, **the number of panels needed** are: 10450/250 = 41.84 ≈ 42 panels.

And according to appendix C, the dimensions of each panel are: 1,640 x 1,000 x 34mm. Then, the surface of each panel is 1.6 m². Therefore, the space needed for all panels is: 1.6*42=67.2 m².

For the inverter, since we need 10450 Wp, (see table 3), we need two Sunny Boy 5000TL inverters since each one has a maximum input DC power of 5250 Wp.

The maximum Power Point Voltage range / rated input voltage for the Sunny boy inverter is from 175V to 500V with an ideal value of 400V (see Appendix E). Each series of panels (11 panels) will give us a voltage of 330, which is within the inverter’s input voltage range. The overall power needed is 25930 Watts which means that we need four charge controllers “Sunny Island 5048” (5000 watt for each). It will be costly, therefore we’ll cover
only 60% of the total power (all appliances are in load) since not all appliances will be used at the same time.

The system needs also a fuse that is also called fuse circuit breaker. It is a safety device which cuts the electric current during a short circuit or overload.

**Battery sizing:**

\[
C_{10} = \frac{E \cdot \text{day (autonomy of 1 day)}}{0.5 \cdot \text{Minimum distortion rate} \cdot 48}
\]

=1619Ah is the capacity of the battery

Therefore the battery needs a capacity of 1619 Ah to make all the appliances work for one day without solar energy nor the grid. According to Appendix F we need a Battery Voltage of 48V and according to Appendix D we will need 24 batteries in series because each battery has a voltage of 2V.

The following figure 8 is a schematic representation of the PV system needed for this case study:
Figure 8. Schematic representation of the PV system needed for this case study.
The return on investment:

According to the National Office of Electricity (ONE), which is the only Moroccan operator of electricity supply in the country, the price of 1kWh is 0.9Mad (including VAT). For this case study we need 38.85kWh/day. Therefore, the annual cost will be:

$$0.9(\text{Mad/kWh}) \times 38.85(\text{kwh/day}) \times 365(\text{day/year}) = 12762.2(\text{Mad/year})$$

Now, we have to estimate the cost of our system. I’ll base my estimation on the invoice prepared by EUROSOL ENERGY SOLUTION (see Appendix G) for AL AKHAWAYN UNIVERSITY for the PV installation that satisfies a total power of 1kWp composed of four 250kWp solar panels.

The estimated cost of a PV with 1kWp: 7628 MAD

The total Power needed for our system: 10.45 kWp

⇒ The estimated cost for all panels: $7628 \times 10.45 = 79712$ Mad without logistics and other materials prices and maintenance.

The estimated cost for logistics maintenance and other materials prices (based on the invoice prepared by EUROSOL ENERGY SOLUTION Company) is about: 40000 Mad.

⇒ The total estimation of the installation of the PV system is

$$79712 + 40000 = 119712\text{ Mad}$$

*The Return on investment*: $\frac{119712(\text{Mad})}{12762.2(\text{Mad/Year})} = 9.38$ Years

**Remark:**

This is just an estimated cost and it was based on the invoice already prepared by EUROSOL ENERGY SOLUTION Company. It is mentioned in the future work that a new invoice should be prepared for a better estimation. We contacted two companies located in Morocco: Atlas Solaire and EUROSOL ENERGY SOLUTION Company and we are still waiting for the new official invoices.

*Interpretation of results:*

The return on investment is approximately 9 years. Which means that households need 9 years to get back their initial investment. It should be taken into consideration that in this case
study we are estimating the worst case scenario, which means that all appliances are working in the same time (maximum load). This means that the return on investment is lower than 9 years.

The return on investment period is long because of the high costs of installation of PVs is high. Morocco imports PV panels and materials from abroad which makes them more expensive because of transportation fees. In addition, there isn’t much competition in Morocco in this sector which makes prices high comparing with other countries.

4. RENEWABLE ENERGY IN THE MOROCCAN CONTEXT

Renewable energy is increasingly at the heart of conversations and political debate in Morocco. In a context of rising oil prices, with a heavy impact on the trade balance of Morocco, renewable energies represent the most interesting alternative to reduce the economic vulnerability of countries in the energy sector.

The potential studies developed so far in the field of solar energy in Morocco determine, on the basis of the surface, the theoretical and technical national potential, which is huge because of the intensity of solar radiation and availability large spaces: a study of GTZ (now GIZ) in 2008 figures estimated the technical potential for the production of electricity from solar power to about 40,000 TWh per year - equivalent to about 1,500 times of the current consumption of electricity and shows - given the increased competitiveness of technologies - the enormous strategic importance of solar energy for Morocco.[22]

In his speeches and in the "High Royal Orientations", His Majesty King Mohamed VI has dedicated the regenerative energy and energy efficiency a significant time. In the "Assises de l'Energie" in 2009 that represents the biggest event for Moroccan local authorities in the field of energy. This meeting represents an opportunity to present the goals set by the new energy strategy of Morocco, which aims to control the country's energy future to ensure its sustainable development. This event was Organized by the Ministry of Energy, Mines, Water and Environment, the meeting also aims to share with a wider audience of professionals and users issues and major challenges of energy Morocco and the need to implement the solutions proposed to achieve the objectives set by the strategy. These Energy first sittings will therefore be an opportunity to highlight the need for energy and optimize its use to promote economic and social development. During this sittings, the government has set an 8% of regenerative energies in primary energy consumption and 18% of electricity needs for
The national program in the sector of solar energy (Integrated Project of solar power production - 2,000 MW by 2020) was introduced in November 2009, the wind program, also 2,000 MW, in July 2010. At the institutional level, the essential basics for the implementation of these programs were asked; for the implementation of the solar project, the "Moroccan Agency for Solar Energy" (MASEN) was founded. The "Center of Renewable Energy Development» (CRED) is transformed into an "Agency for Development of Renewable Energy and Energy Efficiency" (ADREEE), which allows the integration of energy efficiency in the portfolio of this National Agency.

A global fund of 1 billion$, to which Saudi Arabia, the UAE and the Hassan II Fund has contributed, should support primarily the promotion of regenerative energies and energy efficiency, in equal shares for profitable projects and grant projects. To support of so-called "profitable" projects, the "Energy Investment Company", a semi-public company that should support projects for the use of renewable energy sources (including biomass) as well as the creation of companies through participatory capital [22]. The "Energy Development Fund" supports projects that are considered unprofitable such as studies, research and development, and also for example the recapitalization of ONE.

Another political process which importance was graced by His Majesty King Mohamed VI, in his speech in the 6th of November 2014, is regionalization [22]. This process is of great importance to renewable energy, insofar as compared to fossil fuel plants, they should be much more decentralized; this means that many more actors - including the private sector and individuals - are involved in decisions about their exploitation and production of electricity.

4.1 Creation of favorable conditions, incentives, support measures

The creation of promotional legislative requirements such as the integration of low voltage in the Law 13-09 by a Decree / order and simple administrative procedures are essential prerequisites for the realization of the existing potential.

Certainly, the initial investment volume compared to investment opportunities available to the majority of the Moroccan population, is a significant barrier to the achievement of household self-supply by the photovoltaic in Morocco.
In this context, to accelerate the introduction of photovoltaics, it is essential to offer incentives - for example in the form of: investment grants, the decrease in value added tax or the granting of good loan conditions – at least for a limited period, as well as other support measures (marketing measures for awareness, learning and continuing education, support for business creation / strengthening of the industrial fabric …).

4.2 Energy reserves and regulation

It should be noted that other power generation options normally present in a region (wind, hydro, biomass power plants using fossil fuels) should be maintained and retained for the future as reserve energy over the non-existent or insufficient solar radiation phases (night overcast). In this sense, the photovoltaic potential is a maximum value for a power generation closer to consumers, that should not automatically be used, but remain available for growing needs. This issue needs further investigation as part of more detailed scenarios.

4.3 Impact on the national electricity grid

With the rising number of photovoltaic installations worldwide, arise to a greater extent the question of the attitude of this technology for integration into the network of distribution and transmission. PV supplies electricity during the day depending on the intensity of solar radiation. For use with an approach as necessary, as discussed in this study, the photovoltaic allows to operate load shedding during the day: it is related to the peak load of the mid-day which will increase in the future due to the massive installation of air conditioners and the increased needs of the industry. To cover the evening peak consumption so typical of Morocco, the PV does answer - at least at first. The problem can exclusively be solved at the level of the entire electrical system (management stations and the network, Demand Side Management / DSM, storage / STEP).
5-GENERAL DESCRIPTION OF THE SMART HOME ENERGY MANAGEMENT SYSTEM

5-1 SMART PLUG

5-1-1 Smart plug definition:
The smart plug is the part of the system that will enable the control and the monitoring of appliances. It basically consists of a box connected to the power supply and to which the user connects the appliance. The smart plug is composed of a microcontroller, a set of sensors, an Xbee radio, and a relay box.

5-1-2 Smart plug components

Arduino Uno:
The Arduino Uno is a microcontroller board based on the ATmega328 (Figure 9). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The arduino Uno is the microcontroller used in the Smart Home Energy Management System. It is linked to a 9V battery and it also supplies the different sensors through a 5V and a ground pins. The analog pins of the Arduino are connected to the different sensors and the relay to allow the monitor and control of the appliances. This microcontroller also serves as a support for the radio communication.

Figure 9. Arduino Uno [17]
**Xbee ship**

The Xbee ship is a radio that has an embedded solutions providing wireless end-point connectivity to devices. This ship is the component that allow the communication between the smart plug and the gateway. All information sent to and received from the device should be processed by the Xbee ship. The XBee radio series 2 manufactured by Digi International and illustrated by figure 13, enables a wide range of wireless communication protocols including Zigbee. The XBee radios are programmed using terminal programs X-CTU developed by Digi International. The following figure10 is an Xbee Radio Series2.

![Image of Xbee Radio Series 2](image)

**Figure 10. Xbee Radio Series 2 [18]**

**Light sensor**

The light sensor, illustrated in Figure 11, is connected to one of the Arduino analog pins. The light sensor determines the lightening level of a room, and matches it with the local hour, the season and the changing price of electricity. By doing so, it will be possible to increase or decrease the light lever using a voltage divider. The Light Sensor used SEN 11302P and shown in figure 16 incorporates a light dependent sensor (LDR). The resistance of the LDR or Photoresistor will decrease when the ambient light intensity increases.
The temperature sensor is also connected to an Arduino analog pin. This sensor enables us to find the ambient temperature of the room. This temperature is useful when linked to other data as for example the season, the weather conditions, the customer’s preferred temperature and the dynamic pricing of electricity. By doing so, it will be possible to adjust automatically the temperature. The Temperature Sensor used is SEN 23292P as shown in Figure 12, uses a Thermistor to detect the ambient temperature. The resistance of a thermistor and the ambient temperature are inversely proportional, when the resistance of the thermistor increases, the ambient temperature decreases.

The current sensor used, showed in figure13, is a 14is a split-core YHDC STC 013-030 CT sensor which is non-invasive sensor that can sense a current up to 30A and outputs a voltage value of maximum 1V to be interpreted accordingly. A current sensor is a device
that enables the monitoring of the current flowing through the appliance. This sensor needs to be connected to the wire going from the relay box to the appliance. It is then linked to a voltage divider and then to one of the Arduino’s analog pins. By knowing the amount of current flowing through an appliance, we are able to first deduce the state of the appliance (ON or OFF) and second to compute the power consumption of the appliance.

Figure 13. Temperature sensor[25]

- **Breadboard**
  
The breadboard is used to gather the overall sensing system and have a compact block along with the Arduino.

- **Relay box**
  
The Relay box is responsible of the control part of the smart plug. We can’t rely only on the Arduino because the power given by the arduino pins is not sufficient.
5.2 Gateway

5.2.1 Gateway description:

The gateway is a device that enables the communication between the various smart plugs and the webserver hosting the Home Management System application. The gateway consists of an Arduino Uno, an Xbee radio, Ethernet Shield, and a power supply. Figure 14 depicts how all the previously mentioned components are connected together inside the gateway.

![Gateway prototype](image)

**Figure 14. Gateway prototype**

5.2.2 Gateway components description:

- Arduino Uno
- Xbee shield

As we have already mentioned, the Arduino Uno is the support of the radio communication. An Xbee shield is placed on top of the Arduino to connect the various Arduino pins to a new sets of pins compatible with the Xbee ship pins. The Xbee shield is a platform that allow the connection of the microcontroller to the Xbee radio. The Xbee shield represented in figure 15, allows an Arduino board to communicate wirelessly using Zigbee. This Shield will be used to interface the XBee radio Series 2 with our Arduino boards. The Xbee Shield is responsible of the double Xbee wireless communication between the smart plugs and the gateway.
The Arduino Ethernet Shield illustrated in Figure 16 allows an Arduino board to connect to the internet. It is based on the Wiznet W5100 ethernet chip. The Wiznet W5100 provides a network (IP) stack capable of both TCP and UDP. It supports up to four simultaneous socket connections. Use the Ethernet library to write sketches which connect to the internet using the shield. The ethernet shield connects to an Arduino board using long wire-wrap headers which extend through the shield. This keeps the pin layout intact and allows another shield to be stacked on top. It is used to connect the gateway to the database.

Figure 16. Ethernet Shield [27]
6- Implementation of a Smart plug in a Home Energy Management System

During this capstone project, the main objectives that were achieved can be divided into two categories. First the intensive research and literature review helped achieve a good understanding of the smart grid field. Second in the smart grid research lab, we continued the work done by previous capstone students, the concrete outputs: Reading data from sensors was previously implemented, we developed this part by adding two-ways communication between the smart plugs and the gateway and the flow of information to the database.

The purpose of this test is to remotely send the data collected with the sensors from one station to another using the Xbee communication protocol and a star topology. Two end node stations will be sending data to the same base station in order to determine the presence of any possible interference between the two end node stations. The problem that the previous research team was facing was the use of the Arduino Yun in the gateway, the main problem is the absence of a reliable wireless communication. In order to solve this issue we’ll use an Arduino Uno and to afford communication with the database, an Ethernet shield will be used.

6.1 ARDUINO DIRECT SENSORS READING

6.1.1 ARCHITECTURAL DESIGN

The purpose of this test is to display on a computer using serial communication the data collected with the three different sensors.

The figure represents the schema followed in this test. An Arduino Uno connected to three different sensors using analog pins is displaying the readings through serial communication.
6.1.2 ARDUINO UNO CONFIGURATION

In order for the Arduino Uno to display the data readings through the serial connection, the following code in figure 18 was uploaded.

```c
#include < XBus.h > // include Header File
#include "Emonlib.h" // Include Emon library
#define MSG_LEN 10 // Message Length that we will send

// Declaring an energy monitor (from library)
EmonMonitor emon1;

//
int relay = 13; // the relay pin

void setup() {  
  Serial.begin(5600); // Set Serial Communication
  emon1.current(1, 111.1); // Set Energy Monitor Current: input pin, calibration.
  pinMode(relay, OUTPUT); // set the relay pin to output mode
}

void loop() {

  int TemperatureSensorValue, LightSensorValue; // Declare Sensor Variables
  double Irms = emon1.calcIrms(1480); // Calculate Apparent Current

  LightSensorValue = analogRead(A5); // Read Light Sensor value
  Serial.print("LightSensor:"); // Print Light Sensor value to Serial Display
  Serial.println(LightSensorValue);
  Serial.print("Temp: "); // Print Temperature Sensor value to Serial Display
  Serial.println(TemperatureSensorValue);
  delay(1000);
}
```

Figure 17. Architectural Design-Sensor Reading
The main goal of this step was achieved which was the proof of concept of being able to read data from different sensors.

6.2 XBEE SENSOR READING –PAIR TOPOLOGY–

6.2.1 ARCHITECTURAL DESIGN

The purpose of this test is to remotely send the data collected with the sensors from one station to another using the Xbee communication protocol.

Figure 19. Architectural Design - Data communication

The figure 19 represents the schema followed in this test. A computer is connected to (a coordinator station) an Arduino Uno with an Xbee shield and an Xbee chip connected through USB to a computer. Another Arduino with an Xbee shield and an Xbee chip is connector to the circuit of sensors, this is the (router station).
6.2.1 ROUTER NODE

The router node or end node station is composed of the following hardware pieces:

- **An XBee Shield**: used as a communication platform between the XBee chip and the ARDUINO UNO.
- **An XBee Series 2**: collects sensing readings from the Arduino and transmit the information to the base station
- **An ARDUINO UNO**: contains an Arduino program that reads the serial output used as communication platform between the Xbee chip and the sensors
- **A sensors’ circuit**: collects data from the environment.

6.2.2 COORDINATOR NODE

The coordinator node or base station is composed of the following hardware pieces:

- **An XBee Shield**: used as a communication platform between the XBee chip and the ARDUINO UNO.
- **An XBee Series 2**: used to receive sensing readings sent from the radio of the end node station.
- **An ARDUINO UNO**: used as communication platform between the Xbee chip and the computer.
- **An Ethernet shield**: used as a communication platform between the coordinator and the database

The results of the test 2 were very conclusive since the obtained results displayed on the serial monitor were similar to the one obtained from the direct sensors’ reading as shown in Figure 41.

6.3 XBEE SENSOR READING – STAR TOPOLOGY–

6.3.1 ARCHITECTURAL DESIGN

The purpose of this test is to remotely send the data collected with the sensors from one station to another using the Xbee communication protocol and a star topology. Two end node stations will be sending data to the same base station in order to determine the presence of any possible interference between the two end node stations.
The configuration of the Xbee radios:

In order to establish a star communication topology between two XBee radios, a number of attributes proper to each XBee radio have to be set using the terminal program X-CTU.

1) **The pan address of both radios needs to be similar**

2) **Both radios need to be set on API mode**

Figure 20 represents the schema followed in this test. A computer is connected to (a coordinator station) an Arduino Uno with an Xbee shield and an Xbee chip connected through USB to a computer. Two end node stations are then installed, each of them is constituted of an Arduino with an Xbee shield and an Xbee chip then the Arduino is connected to the circuit of sensors.

![Diagram of architectural design of two smart plugs sensor reading](image)

**Figure 20. Architectural design of two smart plugs sensor reading**

### 6.3.2 RESULTS

The results of this phase demonstrated that even if both end node stations are sending sensors’ reading to the base station at the same, no interferences were produced. The data received from each station (Arduino 1 or Arduino 2) is correctly displayed.

### 6.3.3 Data logging

The data logging is crucial in this project since it will allow the construction of representative graphs such as the general consumption profiling and eventually manage the appliance using a
dynamic pricing scheme. After testing the star topology the data needed to be stored in the system’s database. For this purpose, the Ethernet shield is going to be used to enable the data to be send to the database after reception from the Xbee radios.

### 6.4 WIRELESS SENSING AND CONTROL NETWORK

In this step we integrate the work that have been done in the smart plugs with the work performed by capstone student Sofia Ait Bellah relative to remote control of appliance using the exact same hardware components.

#### 6.4.1 ROUTER NODE

The end node base would be configured the same way this was done in the previous part using the API mode. However, the Arduino of this station will have a different code. In the previous part, which was only concerned by the sensing function, the Arduino code had three function that read the light sensor value, temperature sensor value, current sensor value. Other functions were added to this part to enable two ways communication between the smart plug and the gateway and also the control of appliances. The additional functions listens for actuation commands from the base station and execute them using the relay and also build the message to be sent and read the message from the gateway. The following Figure21. Represents the code with all the needed functions responsible of the monitoring and control of the smart plug.
#include <Xbee.h>  // Include Xbee library
#include "TelemLib.h"  // Include Telem library
#define MSG_LEN 10  // Message length that we will send

// Declaring an energy monitor (from library)
EnergyMonitor energy;

Xbee xbee = Xbee();  // Make a Xbee Variable
void setup() {
  xbee.setSerial(Serial);  
  Serial.begin(9600);  // Set Serial Communication
  energy.setCurrent(0.01, 1.0);  // Set Energy Monitor Currents input pin, calibration.
  pinMode(relay, OUTPUT);  // set the relay pin to output mode
}

void loop() {

  int TemperatureSensorValue, LightSensorValue;  // Declare sensor variables
  double Ims = energy.calcIms(1480);  // Calculate Apparent Current

  //////////////////////////////////////////////////////////////////////////////////////////
  // LightSensorValue = analogRead(A0);  // Read Light Sensor value
  Serial.print("LightSensor: ");  // Print Light Sensor value to Serial Display
  Serial.println(LightSensorValue);

  //////////////////////////////////////////////////////////////////////////////////////////

  TemperatureSensorValue = analogRead(A4);  // Read Temperature Sensor value
  Serial.print("Temperature: ");  // Print Temperature value to Serial Display
  Serial.println(TemperatureSensorValue);

  //////////////////////////////////////////////////////////////////////////////////////////

  Serial.print("Current and power: ");  // Print Power and Current Values to Serial Display
  Serial.println(Ims * 220.0);  // Print Power and Current Values

  // Compute Apparent power
  Ims = Ims * 220;

  //////////////////////////////////////////////////////////////////////////////////////////

  String Plug = "Plug 1: ";
  String exp = " ";
  String exp = Plug + exp + LightSensorValue + exp + TemperatureSensorValue + exp + Ims;

  Serial.print("Simple Xbee Communication-Transmitter");
  for (byte i = 0; i < exp.length(); i++) {  // to fill the payload character by character
    payload[i] = exp[i];
  }
  xbee.send(msg);  // send the message

  //////////////////////////////////////////////////////////////////////////////////////////

}
6.4.2 RESULTS

In the same time the sensing is operating, the control of the appliance is achieved. In parallel to this information is sent from both smart plugs to the gateway and the communication is also available from the gateway to the smart plugs. Figure … represents the Serial Arduino display for both smart plugs.

Figure 21. Smart plug Arduino code
The serial monitor box of the coordinator node retrieved the data in Figure 22. Each time it sends data to the gateway it sends the 64-bit source address (ex: 13A200-40ABBC39).

6.4.3 CORDINATOR NODE

The following Figure represents the code uploaded in the Arduino Uno of the gateway. The gateway receive the sensed values from both Smart plugs. The data are received with their corresponding smart plug Mac addresses and classified depending on their address.
#include <XBee.h>  //Include Header File
#include <SPI.h>
#include <Ethernet.h>

#define MSG_LEN 18  //Message Length
// Enter a MAC address for your controller below.
// Never Ethernet shields have a MAC address printed on a sticker on the shield
byte mac[] = { 0x50, 0xA1C, 0x0DA, 0x0F, 0x59, 0x3F };
// if you don't want to use DNS (and reduce your sketch size)
// use the numeric IP instead of the name for the server:
// IPAddress server(192,125,232,129);  // numeric IP for Google (no DNS)
char server[] = "www.caprealty.ma";
char inString[32];  // string for incoming serial data
int stringPos = 0;  // string index counter
boolean startRead = false;  // is reading?
// Set the static IP address to use if the DHCP fails to assign
IPAddress ip(192, 168, 0, 177);
//String sensedData;
uint8_t payload[MSG_LEN];
//XbeeAddress64 addr64 = XbeeAddress64(0x0013A200,0x405022C7);
//define 64-Bit Xbee Address of the Remote Host
XbeeAddress64 addr64 = XbeeAddress64(0x0013A200,0x40AF1BF3);
//XbeeAddress64 addr64 = XbeeAddress64(0x0013A200,0x408C072B);
ZBtxRequest zBtx = ZBtxRequest(addr64, payload, sizeof(payload));  //Make a Xbee Packet

//#define MSG_LEN 15 //Message Length
Xbee xbee = Xbee();

void loop() {
  String pageValue = connectAndRead();  //connect to the server and read the output
  Serial.println("Simple Xbee Communication-Receiver");
  xbee.readPacket();
  //Reads all available serial bytes until a packet is parsed,
  if (xbee.getResponse().isAvailable()) {
    //something available?
    if (xbee.getResponse().getApId() == 2B_RX_RESPONSE) {  //is it rx
      //now get the payload
      xbee.getResponse().getZBxResponse(x);
      Serial.print("Receive packet from (64-bits address)-> ");
      //type:XbeeAddress64
      Serial.println(x.getRemoteAddress64().getMsD(), HEX);
      Serial.println(":");
      Serial.println(x.getRemoteAddress64().getLsb(), HEX);
  }
Serial.print("Packet length is -> ");
Serial.println((tx.getDatLength()), HEX); //getDatLength() type:uint8_t, returns the length of the payload.
//tx.getDat();
//print the payload
Serial.println("The packet ...");
Serial.print(",");
for (byte i=0;i<tx.getDatLength();i++)
    Serial.print(char(tx.getDat(i)));
//sensorData[i] = char(tx.getDat(i));
}
//connectAndWrite(sensorData);
Serial.println(" ");

Serial.println("Simple Xbee Communication-Transmitter");
for (byte i=0;i<sensorValue.length();i++)
    xbee.send(bTx);

Figure 23. Gateway Arduino code

6.4.4 RESULTS

The following Serial Arduino display (figure 24) represents the way information is received and displayed in the gateway.
The serial monitor box of the coordinator node retrieved the data in Figure…. Each time it sends data to the gateway it sends the 64-bit source address (ex: 13A200-40ABBC39). It sends the

6.5 SYSTEM INTEGRATION WITH APPLICATION

This section is about the integration of the system with the web application. The used base station is the Arduino Uno and using the Ethernet shield we can connect to internet. It is very essential to use the Ethernet shield in this phase since the integration requires that the system sends data to the database of the web application. Php files are send to the web server using Ethernet. The Php files are indeed able to access the database and either read from it a particular information or write a change of status.

The database Entity Relationship Diagram used for this application is illustrated in Figure 25, while the interface of the Android Application is presented in Figure.
The coordinator node, Arduino Uno, has to be equipped with an Xbee shield and an Xbee ship in order to communicate with the Smart plugs, while the Ethernet Shield is used between the coordinator node and the web server.
7- COST STUDY

The cost study offers another aspect of evaluation to the system. If the STEEPLE model focused on the macro-environmental factors, the cost study has as objective to assess the system’s overall cost. First the price of one smart plug was evaluated, the prices are in MAD since the retailer ‘DerbSellicon’ is Moroccan. In addition to the overall smart plug price Table 4 summarizes the cost of the different components needed.

Table 4. Smart plug price approximation

<table>
<thead>
<tr>
<th>Smart Plug</th>
<th>Price (MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Uno</td>
<td>362.21</td>
</tr>
<tr>
<td>Arduino XBee Shield v1.1 &amp; XBee Series 2</td>
<td>912.60</td>
</tr>
<tr>
<td>Electric Battery 9V 6LR61</td>
<td>62.28</td>
</tr>
<tr>
<td>Powering Cable for 9V Electric Battery</td>
<td>9.60</td>
</tr>
<tr>
<td>Light Sensor SEN23292P</td>
<td>53.82</td>
</tr>
<tr>
<td>Temperature Sensor SEN11302P</td>
<td>53.82</td>
</tr>
<tr>
<td>Non-invasive Current Transformer Sensor</td>
<td>88.20</td>
</tr>
<tr>
<td>Arduino Breadboard Bundler</td>
<td>192.60</td>
</tr>
<tr>
<td>Relay Control PCB</td>
<td>71.10</td>
</tr>
<tr>
<td>Relay SPST-NO Sealed – 30A</td>
<td>53.10</td>
</tr>
<tr>
<td>Common BJT Transistor – NPN 2N3904</td>
<td>12.00</td>
</tr>
<tr>
<td>Super Bright LED – RED – 10,000mcd</td>
<td>17.10</td>
</tr>
<tr>
<td>Diode Small Signal – 1N4148</td>
<td>5.40</td>
</tr>
<tr>
<td>2x Resistor 1k Ohm 1/6th Watt PTH</td>
<td>18.00</td>
</tr>
<tr>
<td>Screw Terminals 3.5mm Pitch (3-Pin)</td>
<td>19.38</td>
</tr>
<tr>
<td>Screw Terminals 5mm Pitch (2-Pin)</td>
<td>21.66</td>
</tr>
<tr>
<td>10uF capacitor</td>
<td>12.00</td>
</tr>
<tr>
<td>3x Resistor 10k Ohm 1/6th Watt PTH</td>
<td>27.00</td>
</tr>
<tr>
<td><strong>Total Price Smart Plug:</strong></td>
<td><strong>1991.87</strong></td>
</tr>
</tbody>
</table>
Table 5 summarizes the gateway components price and provide an estimate of the gateway total price. Assume a household who owns 20 appliances wants to install the suggested SHEMS, the overall cost, computed on the base of the prototype price, would be 41697.98 MAD.

**Table 5. Gateway Price estimation**

<table>
<thead>
<tr>
<th>Gateway Components</th>
<th>Price (MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino UNO</td>
<td>362.21</td>
</tr>
<tr>
<td>Arduino XBee Shield v1.1</td>
<td>912.60</td>
</tr>
<tr>
<td>XBee Series 2</td>
<td></td>
</tr>
<tr>
<td>Arduino Ethernet shield</td>
<td>389.99</td>
</tr>
<tr>
<td>Electric Battery 9V 6LR61</td>
<td>62.28</td>
</tr>
<tr>
<td>Powering Cable for 9V Electric Battery</td>
<td>9.60</td>
</tr>
<tr>
<td><strong>Total Price Gateway:</strong></td>
<td><strong>1736.68</strong></td>
</tr>
</tbody>
</table>
8- Conclusion

The main motivation behind this work of a SHEMS in a micro-grid is to achieve a higher energy efficiency, to maximize the return on investment of the solar panels, to maximize the utilization of the RE and finally to minimize the dependency on the power provided by the utility company. The primary objective of the capstone project was achieved. This project doesn’t only focus only on the theoretical aspects of the SHEMS but it did yield concrete hardware prototypes.

The first step of this project was the analysis of the possibility of having a photovoltaic system for power generation in our home energy system. In this step, a case study analysis was done for a chosen typical home. After the cost analysis, we can conclude that renewable energy use is still difficult to implement in the Moroccan context because of the limited resources in terms of materials needed.

The second part of the project consisted of monitoring and control of appliances in a Home Energy Management System. The first phase was the collection of data from sensors. Then, using Xbee communication protocol, communicate this data with the gateway. After that, make sure that there is both way communication between the smart plugs and the gateway. The last phase, data must be transmitted to the database through the Ethernet.

The last part merged the work done (monitoring and control) with the application development done by teammate Mohammed Bakr Sikal which gave a strong aspect to the project.

The limitations on the project could be stated as follow: first the high cost of the system implementation. Second, the delay in the control part. Then, lack of accuracy of the current sensor and the absence of voltage sensor and other sensors like: humidity, motion, gas, etc in the lab. Finally, the inability to calibrate the light sensor because of the absence of the Lux meter from the lab.
9-Future Work

In the context of the SHEMS, a number of future projects could be undertaken to complete and enhance this capstone project:

- The implementation of the sensing network using both a current sensor and a voltage sensor along with adding sensors (i.e.: humidity, motion, gas…).
- Second, the deployment of the system in a sample of Moroccan households to generate a Moroccan consumption profile.
- Third, enhancing privacy and security of the data communicated within the system.
- Fourth, Enhancing the system’s intelligence by using optimization algorithms.
- Fifth, A new invoice should be prepared to estimate the cost of the photovoltaic system.
12. References

[1] La consommation d'électricité en chiffres, Retrieved from:


11. Appendices

Appendix A: Irradiation in Ifrane from the European Commission Joint Research Center

Photovoltaic Geographical Information System

Incident global irradiation for the chosen location

Location: 33°51’22” North, 6°03’39” West, Elevation: 1653 m a.s.l.

Optimal inclination angle is: 30 degrees

Annual irradiation deficit due to shadowing (horizontal): 6.2 %

<table>
<thead>
<tr>
<th>Month</th>
<th>H0h</th>
<th>H0pt</th>
<th>H(30)</th>
<th>Hopt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>2770</td>
<td>4110</td>
<td>4520</td>
<td>57</td>
</tr>
<tr>
<td>Feb</td>
<td>3660</td>
<td>4930</td>
<td>5190</td>
<td>50</td>
</tr>
<tr>
<td>Mar</td>
<td>5118</td>
<td>5990</td>
<td>5900</td>
<td>37</td>
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<td>Apr</td>
<td>6780</td>
<td>6010</td>
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<td>May</td>
<td>6360</td>
<td>6020</td>
<td>5130</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>6478</td>
<td>6730</td>
<td>5480</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>7350</td>
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<td>Dec</td>
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</tr>
<tr>
<td>Year</td>
<td>5050</td>
<td>5630</td>
<td>5390</td>
<td>30</td>
</tr>
</tbody>
</table>

H0h: Irradiation on horizontal plane (Wh/m²/day)
H0pt: Irradiation on optimally inclined plane (Wh/m²/day)
H(30): Irradiation on plane at angle 30°deg. (Wh/m²/day)
Hopt: Optimal inclination (deg.)
Appendix B: Solar Panels SOLON220/16 Electrical and Thermal data

### SOLON 220/16

#### SOLON Black 220/16 (monocrystalline)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage (V&lt;sub&gt;mp&lt;/sub&gt;)</td>
<td>20.7V</td>
</tr>
<tr>
<td>Open circuit voltage (V&lt;sub&gt;OC&lt;/sub&gt;)</td>
<td>28.1V</td>
</tr>
<tr>
<td>Short circuit current (I&lt;sub&gt;SC&lt;/sub&gt;)</td>
<td>0.02A</td>
</tr>
<tr>
<td>Maximum power (P&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>250 W</td>
</tr>
</tbody>
</table>

#### Electrical data - typical (STC)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power rating (P&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>250 RP</td>
</tr>
<tr>
<td>Module efficiency</td>
<td>15.1%</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>20.7V</td>
</tr>
<tr>
<td>Rated current</td>
<td>8.47 A</td>
</tr>
<tr>
<td>Open circuit voltage (V&lt;sub&gt;OC&lt;/sub&gt;)</td>
<td>28.1V</td>
</tr>
<tr>
<td>Short circuit current (I&lt;sub&gt;SC&lt;/sub&gt;)</td>
<td>0.02A</td>
</tr>
<tr>
<td>Maximum power (P&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>250 W</td>
</tr>
</tbody>
</table>

#### Thermal data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;s&lt;/sub&gt; of open circuit voltage</td>
<td>-0.23 °C/K</td>
</tr>
<tr>
<td>T&lt;sub&gt;s&lt;/sub&gt; of short circuit current</td>
<td>0.04 °C/K</td>
</tr>
<tr>
<td>T&lt;sub&gt;s&lt;/sub&gt; of power</td>
<td>-0.82 °C/K</td>
</tr>
</tbody>
</table>

#### Rated Voltage of each panel

- Voltage: 20.7V
- Open Circuit Voltage: 28.1V
- Short Circuit Current: 0.02A
- Maximum Power: 250 W

*Stc (Standard Test Conditions): 1000W/m², 25 ± 2°C, AM 1.5, in accordance with IEC 61215.
Appendix C : Solar Panels SOLON220/16 Specifications

SOLON 220/16
SOLON Black 220/16 and SOLON Blue 220/16.

Mechanical specifications
- Dimensions (W x D) 1,040 x 1,000 x 24 mm
- Weight 18.2 kg
- Junction box: 1 junction box with 3 bypass diodes (IP65)
- Cable: Solar cables, length 1,000 mm, 4 mm², prefabricated with MC4 combiner plug (IP67)
- Application class: Application class A according to IEC 61701
- Front glass: Transparent toughened safety glass, 3.7 mm
- Solar cells: 60 cells, monocrystalline or polycrystalline 6.62" x 156 x 156 mm
- Cell encapsulation: EVA (Ethylene Vinyl Acetate)
- Back side: Composite film
- Frame: Anodized aluminum frame with varnish profile and drainage holes

Permissible operating conditions
- Temperature range: -40°C to +60°C
- Maximum surface wind capacity: Tested up to 5,400 Pa according to IEC 61215 (Advanced test)
- Resistance against hail: Maximum impact of 25 mm in impact speed of 83 m/s

Guarantees and certifications
- Product guarantee: 10 years
- Performance guarantee: Guaranteed output of 98% for 5 years, 90% for 10 years, 87% for 15 years, 83% for 20 years and 80% for 25 years

This datasheet complies with the requirements of EN 50530:2003. Subject to modifications.
Electrical data without guarantee. SOLON is certified to SO 9001, ISO 14001 and OHSAS 18001.

20 According to SOLON Product and Performance Guarantee.
Appendix D: OPzs Solar Power Batteries overview

### Type overview

**Capacities, dimensions and weights**

<table>
<thead>
<tr>
<th>Type</th>
<th>C_{1.85 V} Ah</th>
<th>C_{1.88 V} Ah</th>
<th>C_{1.84 V} Ah</th>
<th>C_{1.77 V} Ah</th>
<th>Max. Weight kg</th>
<th>Length mm</th>
<th>Width W mm</th>
<th>Height H mm</th>
<th>Fig</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 OPzS solar power</td>
<td>220.0</td>
<td>208.0</td>
<td>224.0</td>
<td>233.0</td>
<td>181.5</td>
<td>27.2</td>
<td>196</td>
<td>208</td>
<td>A</td>
</tr>
<tr>
<td>5 OPzS solar power</td>
<td>340.0</td>
<td>321.0</td>
<td>337.0</td>
<td>356.0</td>
<td>227.0</td>
<td>29.5</td>
<td>126</td>
<td>208</td>
<td>D2</td>
</tr>
<tr>
<td>6 OPzS solar power</td>
<td>460.0</td>
<td>441.0</td>
<td>457.0</td>
<td>476.0</td>
<td>272.0</td>
<td>24.3</td>
<td>143</td>
<td>208</td>
<td>A2</td>
</tr>
<tr>
<td>7 OPzS solar power</td>
<td>520.0</td>
<td>498.0</td>
<td>513.0</td>
<td>532.0</td>
<td>347.0</td>
<td>26.9</td>
<td>126</td>
<td>208</td>
<td>A5</td>
</tr>
<tr>
<td>8 OPzS solar power</td>
<td>620.0</td>
<td>590.0</td>
<td>605.0</td>
<td>624.0</td>
<td>414.0</td>
<td>21.5</td>
<td>147</td>
<td>208</td>
<td>B5</td>
</tr>
<tr>
<td>9 OPzS solar power</td>
<td>720.0</td>
<td>685.0</td>
<td>700.0</td>
<td>715.0</td>
<td>481.0</td>
<td>36.1</td>
<td>168</td>
<td>208</td>
<td>B5</td>
</tr>
<tr>
<td>10 OPzS solar power</td>
<td>910.0</td>
<td>860.0</td>
<td>875.0</td>
<td>890.0</td>
<td>550.0</td>
<td>44.8</td>
<td>149</td>
<td>208</td>
<td>B10</td>
</tr>
<tr>
<td>11 OPzS solar power</td>
<td>1120.0</td>
<td>1065.0</td>
<td>1080.0</td>
<td>1095.0</td>
<td>613.0</td>
<td>61.3</td>
<td>215</td>
<td>199</td>
<td>B10</td>
</tr>
<tr>
<td>12 OPzS solar power</td>
<td>1320.0</td>
<td>1265.0</td>
<td>1280.0</td>
<td>1295.0</td>
<td>672.0</td>
<td>74.8</td>
<td>215</td>
<td>199</td>
<td>B12</td>
</tr>
<tr>
<td>13 OPzS solar power</td>
<td>1520.0</td>
<td>1465.0</td>
<td>1480.0</td>
<td>1495.0</td>
<td>732.0</td>
<td>88.0</td>
<td>215</td>
<td>199</td>
<td>B12</td>
</tr>
<tr>
<td>14 OPzS solar power</td>
<td>1720.0</td>
<td>1665.0</td>
<td>1680.0</td>
<td>1695.0</td>
<td>792.0</td>
<td>102.0</td>
<td>215</td>
<td>199</td>
<td>B12</td>
</tr>
<tr>
<td>15 OPzS solar power</td>
<td>1920.0</td>
<td>1865.0</td>
<td>1880.0</td>
<td>1895.0</td>
<td>852.0</td>
<td>115.5</td>
<td>215</td>
<td>199</td>
<td>B12</td>
</tr>
</tbody>
</table>

*C_{100h}, C_{50h}, C_{24h}, C_{10h} and C_{5h} = Capacity at 100 h, 50 h, 24 h, 10 h and 5 h discharge*

**Service life in cycles and Depths of Discharge**

The HOPPECKE electrolyte recirculation system efficiently prevents electrolyte stratification during cyclic application.
Appendix E: The inverter Sunny Boy 5000TL technical properties

<table>
<thead>
<tr>
<th>Technical Data</th>
<th>Sunny Boy 5000TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input (DC)</td>
<td></td>
</tr>
<tr>
<td>Max. DC power factor</td>
<td>5250 W**</td>
</tr>
<tr>
<td>Max. input voltage</td>
<td>750 V</td>
</tr>
<tr>
<td>MPP voltage range / rated input voltage</td>
<td>175 V - 500 V / 400 V</td>
</tr>
<tr>
<td>Min. input voltage / start input voltage</td>
<td>125 V / 150 V</td>
</tr>
<tr>
<td>Max. input current A / input B</td>
<td>15 A / 15 A</td>
</tr>
<tr>
<td>Max. input current per string input A / input B</td>
<td>15 A / 15 A</td>
</tr>
<tr>
<td>Number of independent MPP inputs / strings per MPP input</td>
<td>2 / 1, 2: 1</td>
</tr>
<tr>
<td>Output (AC)</td>
<td></td>
</tr>
<tr>
<td>Rated power (60 Hz, 50 Hz)</td>
<td>4600 W</td>
</tr>
<tr>
<td>Max. AC apparent power</td>
<td>5000 VA***</td>
</tr>
<tr>
<td>AC nominal voltage / range</td>
<td>210 V - 230 V, 240 V - 280 V</td>
</tr>
<tr>
<td>AC grid frequency / rated grid voltage</td>
<td>50 Hz / 230 V</td>
</tr>
<tr>
<td>Max. output current</td>
<td>22 A</td>
</tr>
<tr>
<td>Power factor of rated power</td>
<td>1.0</td>
</tr>
<tr>
<td>Displacement power factor, configurable</td>
<td>0.8 leading... 0.8 lagging</td>
</tr>
<tr>
<td>Phase conductors / connection phases</td>
<td>1/1</td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>Max. efficiency / European efficiency</td>
<td>97% / 96.5%</td>
</tr>
</tbody>
</table>

Protection devices

| Input-side disconnection device |                  |
| Ground fault monitoring / grid monitoring |                |
| DC reverse polarity protection / AC short-circuit protection / O-metrically isolated |              |
| All-pole sensitive residual current monitoring unit |             |
| Protection class (as per IEC 62103) / Overvoltage category (as per IEC 60644-1) |     |

General Data

| Dimensions (W/D/H) | 410 / 510 / 185 mm |
|                   | (16.1 / 20.2 / 7.3 inch) |
| Weight            | 24 kg / 53.3 lb |
| Operation temperature range | -25°C...+60°C /+13°F...+140°F |
| Noise emission (typical) | 25 dB(A) |
| Self-consumption (at night) | 1 W |
### Appendix F: Charge controller Sunny Island 5048 Technical properties

<table>
<thead>
<tr>
<th>Technical data</th>
<th>Sunny Island 5048</th>
<th>Sunny Island 5048-US</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC output (loads)</td>
<td>220 V (200 V - 253 V)</td>
<td>120 V (105 V - 122 V)</td>
</tr>
<tr>
<td>Nominal AC voltage (adjustable)</td>
<td>50 Hz / 60 Hz (45 Hz - 45 Hz)</td>
<td>60 Hz (55 Hz - 65 Hz)</td>
</tr>
<tr>
<td>Continuous AC power at 25 °C / 45 °C</td>
<td>5000 W / 4000 W</td>
<td>5000 W / 4000 W</td>
</tr>
<tr>
<td>AC output power at 25 °C for 30 min / 1 min / 3 s</td>
<td>6500 W / 8400 W / 12000 W</td>
<td>6500 W / 8400 W / 11000 W</td>
</tr>
<tr>
<td>Nominal AC current / max. AC current (peak)</td>
<td>21.7 A / 120 A for 60 ms</td>
<td>417 A / 180 A for 60 ms</td>
</tr>
<tr>
<td>THD output voltage / power factor (cos φ)</td>
<td>&lt; 3 % / -1 to +1</td>
<td>&lt; 3 % / -1 to +1</td>
</tr>
<tr>
<td>AC input (generator or grid)</td>
<td>220 V (172.4 V - 264.5 V)</td>
<td>120 V (80 V - 159 V)</td>
</tr>
<tr>
<td>AC input voltage (range)</td>
<td>50 Hz / 60 Hz (40 Hz - 70 Hz)</td>
<td>60 Hz (54 Hz - 64 Hz)</td>
</tr>
<tr>
<td>AC input frequency (range)</td>
<td>56 A (0 A - 56 A) / 12.8 kW</td>
<td>56 A (0 A - 56 A) / 6.7 kW</td>
</tr>
<tr>
<td>Max. input current (adjustable) / max. input power</td>
<td>120 A / 100 A</td>
<td>120 A / 100 A</td>
</tr>
<tr>
<td>Battery DC input</td>
<td>48 V (41 V - 65 V)</td>
<td>48 V (41 V - 65 V)</td>
</tr>
<tr>
<td>Battery voltage (range)</td>
<td>120 A / 100 A</td>
<td>120 A / 100 A</td>
</tr>
<tr>
<td>Max. battery charging current / continuous charging current at 25 °C</td>
<td>lead, NiCd / 100 - 10,000 Ah</td>
<td>lead, NiCd / 100 - 10,000 Ah</td>
</tr>
<tr>
<td>Battery type / battery capacity (range)</td>
<td>I1UL1 process</td>
<td>I1UL1 process</td>
</tr>
<tr>
<td>Charge control</td>
<td>I1UL1 process</td>
<td>I1UL1 process</td>
</tr>
<tr>
<td>Efficiency / operating consumption</td>
<td>0.5 %</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Max. efficiency</td>
<td>0.5 %</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Over consumption with no load / standby</td>
<td>25 W / 4 W</td>
<td>25 W / 4 W</td>
</tr>
<tr>
<td>Protection devices</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td>DC reverse-polarity protection / DC bus</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td>AC short-circuit / AC overload</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td>Overtemperature / excessive battery discharge</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td>General data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensions (W / H / D) in mm</td>
<td>467 / 612 / 235</td>
<td>467 / 612 / 235</td>
</tr>
<tr>
<td>Weight</td>
<td>63 kg</td>
<td>63 kg</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-25 °C to 450 °C</td>
<td>-25 °C to 450 °C</td>
</tr>
<tr>
<td>Protection rating (as per IEC 60520)</td>
<td>indoor (IP55)</td>
<td>indoor (IP65/1)</td>
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<tr>
<td>Features / function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation &amp; display / multifunction relays</td>
<td>internal / 2</td>
<td>internal / 2</td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-phase systems / parallel connection</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated bypass / multicluster operation</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State-of-charge calculation / bulk / float charge</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated soft-start / generator support</td>
<td>&amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Battery temperature sensor / communication cables</td>
<td>&amp;</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warranty (5 / 10 / 15 / 20 / 25 years)</td>
<td>1/2/2</td>
<td>1/2/2/2/2</td>
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<tr>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessories</td>
<td></td>
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<tr>
<td>Battery cables / battery fixings</td>
<td>0/0</td>
<td>0/0</td>
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<tr>
<td>Interfaces (RS485 / Multicluster PB)</td>
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<td>0/0</td>
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<tr>
<td>“GenMo” extended generator start</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Load shedding controller / battery current measurement</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>● Standard features</td>
<td>○ Optional features</td>
<td>— Not available</td>
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<tr>
<td>Last revision: May 2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type designation</td>
<td>SI 5048</td>
<td>SI 5048-US</td>
</tr>
</tbody>
</table>
# Appendix G: Invoice by EUROSOL Energy Solutions

## PROJET
**ALAKHAWAYN**
**MAROC**

**EUROSOL Energy Solutions Maroc S.A.R.L.**
Rés. Almasjed n°1 Série stage - n°29, Gueliz
40000 Marrakech - Maroc
Tel +212 (0) 6 38 95 80 69
E-mail m.prinz@eurosol.eu

**Adresse de livraison:** Marrakech, Maroc (Adresse à définir)

**Adresse de facturation:** Adressse à définir

**Date de demande:** Début Avril 2014
**N° Tel:** +212 (0) 6 38 95 80 69
**E-mail:** m.prinz@eurosol.eu

**Validité:** 15 jours à compter de la date d'émission de la présente offre

**Devis N° 12-11-14/19-4**

<table>
<thead>
<tr>
<th>C</th>
<th>Désignation</th>
<th>Qté</th>
<th>Prix unit. (Dhs)</th>
<th>Total (Dhs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>MATÉRIEL PHOTOVOLTAIQUE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Panneau solaire Schoten 250W</td>
<td>4</td>
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<tr>
<td></td>
<td>Puissance nominale 250W</td>
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</tr>
<tr>
<td></td>
<td>Renforcement : connecteurs Multi Contact MC-4</td>
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<tr>
<td></td>
<td>Tension sur puissance [V]: 220-240, 50 Hz (Nom)</td>
<td></td>
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<tr>
<td></td>
<td>Encombrements [mm]: 1500 x 1800 x 50</td>
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<tr>
<td></td>
<td>Poids [kg]: 34,0</td>
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<td></td>
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<tr>
<td></td>
<td>Longueur [m]: 21,9</td>
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<tr>
<td></td>
<td>Imp. [A]: 7,83</td>
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<tr>
<td></td>
<td>Vcc [V]: 48,0</td>
<td></td>
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<tr>
<td></td>
<td>Res [A]: 8,31</td>
<td></td>
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<tr>
<td></td>
<td>Tension max [V]: 1200</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Structure de pose pour les modules Schoten</td>
<td></td>
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<tr>
<td></td>
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<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Sous total poste I 1 7 629,00 7 629,00

| II | FOURNITURE PARTIE ELECTRIQUE                      |     |                 |             |
|    | Onduleur Multiplus C2 24V16004A16                | 1   |                 |             |
|    | Grid Inverter BlueSolar 1500 / 230               | 1   |                 |             |
|    | Interrupteur solaire VE Transfer Switch SiVA230V | 1   |                 |             |
|    | Batteries QEL Deep cycle sans entretien 220AH 12V | 2   |                 |             |
|    | Cables de connexion batteries 35mm²              | 2   |                 |             |
|    | HELI/ABEL HK-30-SOLARPLEX-X PVP-F 1X35mm²       | 100m|                 |             |
|    | 1X35mm² Cross section: 1 x 6 mm²                 |     |                 |             |
|    | Connecteur de cable MC4 mâle/femelle            | 4   |                 |             |
|    | Câble control GX                                | 1   |                 |             |
|    | Câble RJ45 pour la connexion de Multiplus et le Control GX | 30 |                 |             |
|    | Precision Battery Monitor BMV-4628              | 1   |                 |             |


Sous total poste II 1 31 556,64 31 556,64

| III | LOGISTIQUE, TRANSPORT & MANUTENTION              |     |                 |             |
|     | Transport de matériel et délivrance par rapport à un groupe de marchandises | 1 | 3 378,00 | 3 378,00 |


Sous total poste III 1 3 378,00 3 378,00

| IV  | INSTALLATION & MISE EN SERVICE                   |     |                 |             |
|     |                                                  | 1   |                 |             |


Sous total poste IV 1 3 660,00 3 660,00

<table>
<thead>
<tr>
<th>Conditions de paiement : (valable pour toutes les devis)</th>
<th>Total H.T. (Dhs)</th>
<th>T.V.A. (20%) (Dhs)</th>
<th>Total T.T.C. (Dhs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Paiement à 100% avec 2% d'acompte (taxe d'interomption)</td>
<td>45 665,84</td>
<td>9 133,17</td>
<td>54 799,00</td>
</tr>
<tr>
<td>- Envoi en charge (excl. TVA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 30 à 45 jours ouvrables</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>