Western Norway University of Applied Sciences

Off-grid Solar Power Systems in Rural Areas

Photo: Haugesund Rotifunk

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Written by: Mette Kristine Breiteig
Trond Hjartåker

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BACHELOR'S THESIS

Students names: Trond Hjartåker
Mette Kristine Breiteig

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Assignment description:
Engineers Without Borders was commissioned by the non-profit organisation Haugesund Rotifunk to look at the possibility of reliable power to Hatfield Archer Memorial Hospital in Rotifunk, Sierra Leone. An off-grid solar power system was chosen.
In our bachelor thesis we will look at the existing electrical system and the new solar power system at the hospital, assessing if sufficient power is delivered for the intended use. Then also evaluate how the system performs in terms of selectivity and safety. Technical drawings of the hospital's system will be produced, in addition to maintenance suggestions, how to best use the two generators on site and proposals on further expansion. Finally we will develop a design guideline that can be used on similar projects in the future.

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Internal tutor: Arjen Kraaijeveld

External tutor: *Asbjørn Lie*
Address external tutor: *Høievegen 103, 5563 Førresfjorden*

Approved by program coordinator: Jorunn S. Nysted
Date: 26/4-17

Western Norway University of Applied Sciences
Department of Engineering
Bjørnsons gt. 45
5528 HAUGESUND
Norway
Phone No: +47 52 70 26 00
Fax No: +47 52 70 26 01

Thesis Off-grid Solar Power Systems in Rural Areas			Report Number
Written by Trond Hjartåker and Mette Kristine Breiteig			
Department Engineering		Study Program B.Sc. Electrical Engineering	
Grading Open	Submitted	Tutors Arjen Kraaijeveld Asbjørn Lie	

Abstract

Engineers Without Borders - Haugalandet was commissioned by the organization Haugesund Rotifunk to review the possibility of providing a reliable power supply at the Hatfield Archer Memorial Hospital in Sierra Leone. An off-grid solar power system was chosen as the best solution. In this thesis, the solar power system has been assessed to see if it is sufficient for its intended use.

The assessment of the ongoing project at the hospital showed that the solar power system is satisfactory, given the invested funds. For the system to be able to provide power to all connected loads, it would need to be expanded. However, with correct use and maintenance, the system should provide a considerable amount of energy, giving the hospital a more reliable power source.

Preface

This bachelor thesis "Off-grid Solar Power Systems in Rural Areas" represents the finishing work of our B.Sc. in Electrical Engineering at the Western Norway University of Applied Sciences, Campus Haugesund. The report is written by Trond Hjartåker and Mette Kristine Breiteig. Two students from diverse study backgrounds, that met for the first time when starting this bachelor project. The cooperation has been successful, with an exclusively positive result.

The thesis is based upon the assessment of the solar power project at Hatfield Archer Memorial Hospital in Rotifunk, Sierra Leone. The project was first carried out by engineers from the organization Engineers Without Boarders-Haugalandet (EWB), were both of us also are members. We started the work with this bachelor project by attending the project planning meetings for the project in Rotifunk. This gave us solid knowledge and background information.

Working with this project has extended our knowledge of solar power systems that none of us had much experience with before. We now understand how the system works, the electrical components involved, and what is important to consider. Due to our work with the project, we will take part in a delegation with two other engineers as representatives for EWB. We will travel to Rotifunk, overviewing the project close-out and the handover of the solar power system in the middle of May 2017.

We wish to extend our greatest gratitude towards our internal tutor, Arjen Kraaijeveld, our external tutor Asbjørn Lie, and Professor Andrès Olivares for all their help, input and constructive feedback. Without their guidance, our work with this project would have proved to be very difficult. A great thank you also goes to Engineers Without Boarders-Haugalandet and Haugesund Rotifunk, who made this bachelor project possible. They are also giving us the opportunity to travel to Sierra Leone, to share our knowledge, and at the same time learn as much as we possibly can. Hopefully, giving us experience that will become useful for similar projects in the future.

Best regards

Haugesund, 8 May 2017

Trond Hjartåker

Trond Hjartåker

Mette K. Breiteig

Mette Kristine Breiteig

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Table of Acronyms and Abbreviations

A	Amps
AC	Alternating Current
AGM	Absorbed Glass Mat
Ah	Amps-hour
C_{20}	The battery capacity if discharged over 20 hours
C.C.	Charge Controller
DC	Direct Current
DOD	Depth of Discharge
EFO	Energy for Opportunities
EWB	Engineers Without Borders
HR	Haugesund Rotifunk
HRC	High Rupturing Capacity
I_{sc}	Short Circuit Current
kWh	Kilo Watt-hours
LCOE	Levelized Cost of Energy
LVD	Low Voltage Disconnect
MPPT	Maximum Power Point Tracker
NOCT	Nominal Operating Cell Temperature
PDP	Power Distribution Panel
PWM	Pulse Width Modulation
UPS	Uninterruptable Power Supply
V	Volts
VA	Volt Amps
V_{oc}	Open Circuit Voltage
PA	Public Address
PV	Photovoltaic
PSH	Peak Sun Hour (kWh/m^2)
PWM	Pulse Width Modulation
SC	Short Circuit
STC	Standard Test Conditions
W	Watt
Wh	Watt-hours
˚C	Degree Celsius

Summary

Hatfield Archer Memorial Hospital in Rotifunk, Sierra Leone was left in ruins after a devastating civil war. In 2005, the non-profit organization Haugesund Rotifunk was founded and put to the task of rebuilding the hospital. Until today a diesel generator has been used to provide electricity to the most essential parts of the hospital. Unfortunately, diesel generators are both expensive and unreliable.

Engineers Without Borders - Haugalandet was by the early spring of 2016 commissioned by the Haugesund Rotifunk organization to look at the possibility of providing a reliable power supply. If anything, Sierra Leone has a great amount of sunshine, and an off-grid solar power system was chosen as the best solution.

The existing electrical system and the new solar power system at the hospital have been assessed in this thesis to see if the delivered solar power system is sufficient for its intended use. To achieve the goal of this report, literature available on solar power, project documents, technical reports & drawings of the hospital, along with the tender from the solar power system supplier, and technical specification sheets for the equipment have been used. Simulations in the PVsyst 6.6.0 Photovoltaic Software Simulation Program have also been carried out. Both authors are members of Engineers Without Borders, and attended the Rotifunk project planning meetings.

The assessment of the ongoing project at the Hatfield Archer Memorial Hospital showed that the installed solar power system is satisfactory, given the invested funds. For the system to be able to provide power to all connected loads, it would need to be expanded. After the installation of the new solar power system, the hospital will still need to rely on the use of a generator to have enough power. However, with correct use and maintenance, the system should provide a considerable amount of clean energy, giving the hospital a more reliable power source.

Sammendrag

Sykehuset «Hatfield Archer Memorial Hospital» lokalisert i Rotifunk, Sierra Leone ble etterlatt i ruiner etter en ødeleggende borgerkrig. I 2005 ble den veldedige organisasjonen Haugesund Rotifunk grunnlagt og satt til å gjenoppbygge sykehuset. Inntil i dag har en dieselgenerator blitt brukt til å gi strøm til de viktigste delene av sykehuset, men dessverre er dieselgeneratorer både dyre og upålitelige.

Ingeniører uten grenser - Haugalandet ble tidlig våren 2016 forespurt av Haugesund Rotifunk for å se på muligheten av å installere en pålitelig strømforsyning til sykehuset. Sierra Leone har mye solskinn, og et «off-grid» solenergisystem ble valgt som den beste løsningen.

Det eksisterende elektriske anlegget og det nye solenergisystemet på sykehuset har blitt vurdert i denne bacheloroppgaven for å se om det installerte solenergisystemet er tilstrekkelig for den tilsiktede bruken. For å nå målet med denne rapporten er det blitt brukt tilgjengelig litteratur om solenergi, prosjektdokumenter, tekniske rapporter og tegninger av sykehuset, sammen med anbudet fra leverandøren av solenergisystemet og tekniske datablader for det elektriske utstyret. Simuleringer i programmet «PVsyst 6.6.0 Photovoltaic Software Simulation Program» har også blitt utført. Begge forfatterne er medlemmer av ingeniører uten grenser og deltok på planleggingsmøtene til Rotifunk prosjektet.

Den helhetlige vurderingen av det pågående prosjektet ved sykehuset viste at det installerte solenergisystemet er tilfredsstillende, gitt de investerte midlene. For at systemet skal kunne gi strøm til alle tilkoblede belastninger må det allikevel utvides. Etter installasjonen av det nye solenergisystemet vil sykehuset fortsatt måtte bruke generator for å ha nok strøm. Allikevel, med riktig bruk og vedlikehold bør systemet gi en betydelig mengde ren energi, noe som gir sykehuset en mer pålitelig strømkilde.

1 Introduction

As an introduction to this bachelor thesis, the first chapter will describe the background, purpose and limitations of the project. No technical knowledge is required, and reading the first three chapters will give a good foundation for understanding. A goal for the authors of this thesis, is to provide useful information to engineers with interest in the project, members of Haugesund Rotifunk, and members of the Hatfield Archer Memorial Hospital

1.1 Background

Sierra Leone is one of the world's poorest countries, ranked as the 181^{st} least developed country out of 188 by the 2015 United Nations Human Development Report (United Nations, 2015). In the period between 1991 and 2002 the country suffered a devastating civil war. Everything that it once was had now been destroyed, 70 000 people had been killed and the population was left behind without fundamental needs, like a working healthcare system (Kaldor & Vincent, 2006, pp. 4-5).

Hatfield Archer Memorial Hospital in Rotifunk was once a large and well -functioning hospital, patients came from all over the country to use its facilities. By 2002 only the building foundations remained and all qualified personnel had fled the country a long time before. In 2005, the non-profit organization Haugesund Rotifunk was founded and put to the task of rebuilding the hospital. The organization, in cooperation with the Norwegian / Sierra Leonean Alton Bendu initiated major fundraising campaigns for money and medical equipment. Doctors, gynecologists, midwives, dentists and surgeons also began to travel from Norway to Rotifunk to assist at the hospital and share their knowledge. The rebuilding of the hospital came to the cost of approximately 4.3 million NOK. Ten years after it all started the hospital finally had its official opening in May 2014 (Foreningen Haugesund Rotifunk).

Until today a diesel generator has been used to provide electricity to the most essential parts of the hospital. Unfortunately, diesel generators are expensive to operate and in a rural town like Rotifunk the delivery of fuel can be a challenge. In other words, a very unreliable power source. Engineers Without Borders - Haugalandet was by the early spring of 2016 commissioned by the Haugesund Rotifunk organization to look at the possibility of reliable power to the Hatfield Archer Memorial Hospital. If anything, Sierra Leone has a great amount of sunshine, and so they decided an off-grid solar power system was the best solution. It is a relatively large one-time investment, but later this will prove to be a comparably maintenance free, inexpensive and stable power supply[1].

Engineers Without Borders began with the planning and designing. A supplier in the capital Freetown was chosen, the funds were raised and the hospital is now looking to have a working solar power system installed by the summer of 2017.

Foreningen Haugesund Rotifunk

ENGINEERS WITHOUT BORDERS NORWAY

Photo: Haugesund Rotifunk

[1] Knowledge from attending Engineers Without Borders project meetings.

1.2 Purpose

The project in Rotifunk does not stand alone as an example of energy needs that exists in rural areas. It can therefore be assumed that Engineers Without Borders will get more requests like this in the future. With the assessment of the ongoing project at the Hatfield Archer Memorial Hospital in this thesis, the authors hope to learn how to best design off-grid solar power systems for similar environments and use. The existing electrical system and the new solar power system at the hospital will be assessed to ensure that the delivered system is sufficient for its intended use.

In short, the main goal can be described as:

- To ensure that Hatfield Archer Memorial Hospital gets a sufficient and reliable power source, with the use of funds available today and the best use of additional funds.
- To guarantee that the delivered power system lives up to its purpose in years to come, despite possible failures or maintenance issues.
- To develop a design guideline that can be used in similar projects. With the intention of making it as easy and efficient as possible to provide a quality solar power system, considering the funds available when needed.

To be able to do this, a deep understanding on how solar power systems work is essential. Knowledge about the electrical system at the hospital, the environment, location and how everything will be connected is also required to do the analysis. To achieve this, the authors will look at the technical reports and documents from the hospital, literature available on solar power, and the technical specifications from the manufacturers. Solar power system simulation programs will also be used.

The main difference with this kind of project compared to what might already be known from Norway, is that the greatest limiting factor is usually the money available. The funds will determine the size of the power system that can be provided. Transportation, weather and maintenance will most likely also be key factors to consider with this kind of installation area. Often donated equipment comes from all over the world, which may not at first hand work well together. In rural underdeveloped areas, the standard of existing electrical systems may vary.

It is a different world, and it is important to find the balance of what is functional, safe, reliable, economical and operationally acceptable.

1.3 Limitations

Based on the scope of the assignment, some limitations had to be specified:

- The analyses are based on the electrical system report made by others who have been at the hospital. The technical specifications of the delivered solar power system is used, in addition to communication with the supplier Energy for Opportunity (EFO). The reports and technical specifications are presumed to be accurate.

- The solar power industry is an ongoing and quickly developing industry. Only the most common solutions available on the market today are discussed in this report.

- Several limitations had to be considered when executing the solar power system simulations.
    - Inverters are not supported in the simulation software with an off-grid solar power system. Therefore, the inverter efficiency had to be taken into account when plotting the daily energy consumption in the program.
    - Data for the chosen battery and solar panel model are not available in the simulation software and had to be inputted manually.
    - A conservative power usage profile had to be chosen. The reason for this is that the delivered solar power system is too small for the total power usage profile, the program would not allow it.

  Please see Chapter 3.5 for further information.

- In the discussions and recommendations, only systems up to 60 kVA are considered. This is appropriate for the chosen products, and will cover the present and future power needs at the hospital. For simplicity, only products from the same manufacturers as in the delivered solar power system are considered

- Some assumptions had to be made due to limited available information.
    - The solar panels are presumed to be connected to the charge controllers in two strings of ten panels each. This is seen as the logical way to connect the 80 solar panels to the four charge controllers.
    - The electrical network is presumed to comply with the utilisation category AC 22 A according to the British Standards - BS EN 60947-3.
    - The 20-kVA generator is presumed to be connected to the electrical system with a manual changeover switch.

- The conservative power usage profile (137 kWh/day) chosen for this thesis is only an estimate of the power usage at the hospital. The actual power usage at the hospital has not been measured.

2 Solar Power Theory

Chapter two presents some basic solar power theory. It explains the concept of an off-grid solar power system, and describes the different components that are needed.

2.1 Basic Concept of an AC Off-grid Solar Power System

A basic design of an off-grid AC solar power system consists of these four components (shown in Figure 2.1):

- Solar Panel
- Charge Controller
- Battery
- Inverter

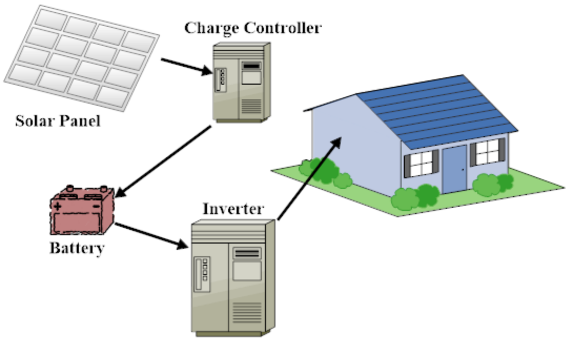

Figure 2.1 - A Basic Design of an AC Off-grid Solar Power System

Energy in the sun beams is absorbed by the solar panels, transforming the energy into power. The power is then fed to the connected charge controller. The charge controllers task is to make sure the batteries does not get damaged by the charge or discharge. This is done by keeping the voltage within set limits. From the charge controller, the batteries and power inverter is connected. If only direct current (DC) components are in the installation, there is no need for an inverter. In an alternating current (AC) system the inverter converts the DC provided by the batteries into AC, ready to power AC powered components. If available or needed, an external generator can be connected to the system, either to the charge controller, inverter or a separate power distribution panel. The connection depends on the intended use of the generator, if used to charge the batteries, or to share the loads in the installation (Gevorkian, 2006, pp. 10-14) .

2.2 Solar Power Panels

Each component mentioned in Chapter 2.1 is important to make use of the electricity, but the main concept of solar power lays within the solar panels and their solar cells.

Solar cells, also called photovoltaic (PV) cells convert sunlight directly into electricity. It is called photovoltaic due to the process where photons from the sunlight converts the energy into electricity and voltage.

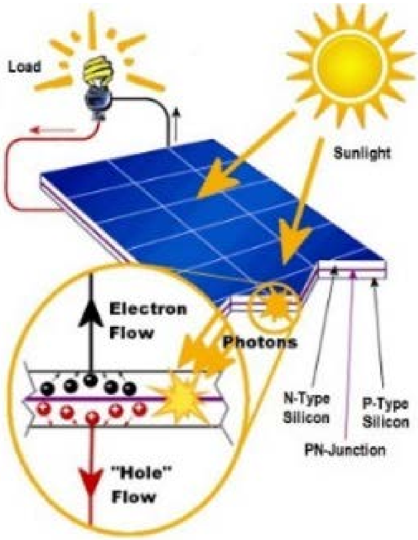

Figure 2.2 - Principle of a Solar Cell. Source: Eurosolar

In a typical solar cell, two diverse types of crystalline silicone are sandwiched between conductive layers. The diverse types of silicon are made by mixing the silicon with other substances to make it more conductive, also called doping. A so-called N-type silicon is used, which is doped to have extra electrons available, making it negatively charged. Then a layer of P-type silicon is used, which has less electrons, making it positively charged. Where the two types of silicon meet, they form a static PN-junction leaving a positive charge on one side, and a negative charge on the other. When a photon from the sunlight strikes the silicon cell with enough energy to knock an electron out from its bond, the electron is leaving a positive hole which is instantly drawn to the negative side of the PN-junction. Because of the electromagnetic field in the PN-junction the electrons can only go one way, leaving the free electron nowhere to settle. The mobile electron is then collected by thin conductive layers at the top of the cell. From where they flow in an external electrical circuit doing electrical work, before they can reunite with their original spot (Gevorkian, 2006, pp. 4-6). The process is shown in Figure 2.2.

Solar power panels consist of multiple solar cells grouped into modules and are electrically connected to increase power. The modules are then covered by a protective sheet and a surrounding frame (shown in Figure 2.3).

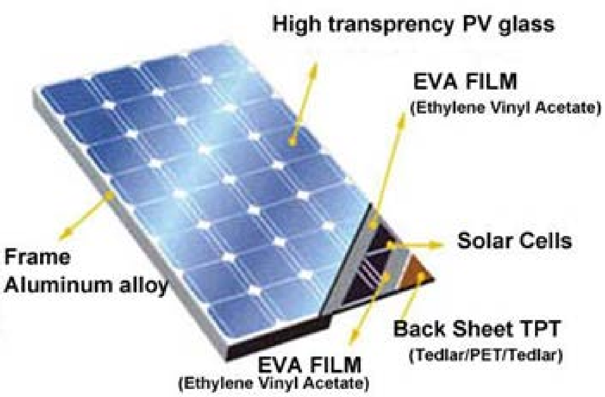

Figure 2.3 - Example of a Solar Power Panel. Source: Pinterest

Three basic technologies are used to produce solar cells for solar power panels:

- **Single-crystal Cells (Mono-Si)** involves slicing long cylinders of silicon into thin wafers. It gives the cells with highest efficiency, but they are energy intensive to produce and use more materials. Single-crystal cells accounted for 23.9 % of the global market for solar power in 2015 (Fraunhofer Institute for Solar Energy Systems, ISE, 2016).

- **Polycrystalline Cells (Multi-Si)** are made of silicon melted into bars, and then sliced into squares. They are cheaper to produce, but the efficiency is lower. Polycrystalline cells accounted for 69.5 % of the global market for solar power in 2015 (Fraunhofer Institute for Solar Energy Systems, ISE, 2016).

- **Thin-film Cells** involve depositing materials onto glass or metal surfaces in thin films. Examples of the most common technologies are: Amorphous Silicon (a-Si), Cadmium-telluride (CdTe), and Copper-indiumgallium-selenide (CIGS). The efficiency of thin-film cells is lower, but it uses less material and can be cheaper to produce. Thin-film cells accounted for 6.6 % of the global solar power market in 2015 (Fraunhofer Institute for Solar Energy Systems, ISE, 2016).

The power output from the solar panels are DC and varies depending on how much solar irradiance the panel is receiving. To enable easy comparison between different solar panels, a nominal peak power capacity (Wp) value is defined. It is measured as the solar panels power output with a solar irradiance of 1000 W/m^2 at 25 °C. Typically this ranges from 100 to 365 watts. The actual power output from a panel will vary depending on the geographical location, time of the day, weather conditions etc. If the temperature of the panel increases, the power output will decline (Sustainable Energy Authority of Ireland, 2009, p. 15).

The electrical efficiency of a solar panel is a key factor when choosing a solar power system. The efficiency describes how much solar energy the panel can convert into electrical power. Generally, a more efficient panel will be more expensive, therefore cost is also a crucial factor when selecting solar panels. If mounting space is limited, solar panels with high efficiency is preferable. If mounting space is not an issue, solar panels with less efficiency can be chosen. In the last 10 years, the efficiency of the average commercial single-crystal cell module increased from about 12 % to 17 %. At the same time, the thin film cell (CdTe) modules efficiency have increased from 9 % to 16 % (Fraunhofer Institute for Solar Energy Systems, ISE, 2016).

The lifetime of a single solar cell can be almost limitless, but due to outer factors like wear of the protective sheet and degradation in the electric circuits, manufacturers generally guarantee 80 % of the peak power for 20-25 years (Sustainable Energy Authority of Ireland, 2009, p. 13).

2.3 Batteries

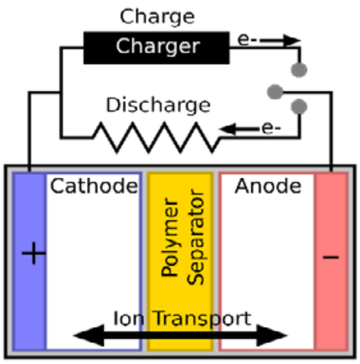

Figure 2.4 - Example of a Battery with Charger and Load. Source: Tkarcher

A battery is a device that can store energy in a chemical form and release it in an electrical form. It consists of one or more cells with a cathode and an anode of different chemical composition with a neutral electrolyte between. When the battery is full, the anode has an oversupply of negative ions, and the cathode has an oversupply of positive ions. When connected through a load, the battery discharges, and negative ions travel through the load to the cathode. This continues until the anode is neutral with an equal amount of positive and negative ions.
If the battery is rechargeable, an external power source can be connected reversing the flow of negative ions back from the cathode to the anode (Gevorkian, 2006, pp. 34-43).
The principle is shown in Figure 2.4.

For solar power systems, two types of batteries are commonly used:

- **Lithium-ion** batteries consists of a carbon anode, a metal oxide cathode and an electrolyte made up of lithium salt in organic solvent. The main advantages are an ability to deliver many cycles in their lifetime, and high charge & discharge efficiency, saving energy. They are also good at keeping the capacity at a full level when idle, useful for installations where energy is only used occasionally. Lithium-ion batteries are also generally light in weight making installation easy (Cadex Electronics Inc, 2016). Lithium-ion batteries are more expensive than lead-acid batteries, but price has dropped significantly in recent years due to increased production for electric cars (US Department of Energy, 2014). Each lithium-ion cell has a nominal charge of 3.6 V

- **Lead-acid** batteries consists of a lead anode, a lead oxide cathode, and sulfuric acid electrolyte. The main advantages are that they have a low cost and can supply high surge currents. Disadvantages are the heavy weight and for flooded lead-acid batteries, the extra maintenance needed due to the electrolyte having to be refilled regularly. Each lead-acid cell has a nominal charge of 2 V, and are often combined to create standard voltages of 6 V, 12 V, 24 V and 48 V (Cadex Electronics Inc, 2016).

A problem that can occur with lead-acid batteries is sulfation and stratification. This decreases the usable battery capacity.

- **Sulfation** is when unwanted lead sulfate crystals gather on the anode, reducing the transport of electrons. It occurs if the batteries are not in use, never fully charged, or are regularly overcharged (Cadex Electronics Inc, 2016).

- **Stratification** is when the electrolyte gathers at the bottom of the cell. It occurs if the batteries are never fully charged or if the batteries are not in use. Absorbed Glass Mat (AGM) batteries and gel batteries does not experience this problem (Cadex Electronics Inc, 2016).

For flooded lead-acid batteries the battery enclosure also needs proper ventilation to avoid hydrogen gas accumulating from reaching dangerous levels. Batteries with AGM or gel technologies do not need maintenance. Gel batteries have a semi-solid electrolyte. AGM batteries have an electrolyte absorbed in fiberglass (Gevorkian, 2006, p. 40).

Due to chemical changes in the electrodes, battery capacity degrades over time. This happens even if the battery is not used. How much the battery degrades depends on the maximum state of charge and the depth of discharge. However, the most important factor is the temperature of the battery. If used or stored at higher temperatures degradation increases. To avoid this, stored batteries should be kept cold, and battery enclosures should be kept below room temperature (25 °C) (Rolls Battery, 2016).

The capacity of a battery is usually defined as the total current the battery can supply for 20 hours at 20 °C while remaining above a specified voltage. For example, a 20 Ah battery can deliver 1 A continuously for 20 hours (Cadex Electronics Inc, 2016).

2.4 Charge Controller

A charge controller in a solar power system regulates the power flowing in and out from the batteries. It ensures that the batteries are not overcharged and prevents the batteries from completely draining, something that can reduce the battery lifetime. A simple charge controller starts charging when the voltage drops below a set level, and stops charging when the voltage exceeds a set level (Gevorkian, 2006, pp. 12,43).

For more advanced charge controllers, two technologies are used:

- A **Pulse Width Modulation (PWM)** controller sends out a series of short charging pulses to the batteries. The controller checks the voltage of the batteries to determine how fast to send the pulses and how long the pulses will be. With a fully charged battery the pulses will be very short and will be sent every few seconds. If the battery is discharged the pulses will be very long and almost continuous. PWM controllers are an old technology and are not very efficient. However, they can be a good choice if the budget is limited, the system is small, and is in a location with steady and strong solar irradiance (Northern Arizona Wind & Sun Inc).

- **Maximum Power Point Tracking (MPPT)** is basically a high frequency DC to DC converter. It takes the DC input from the solar panels and changes it to high frequency AC. It then converts the voltage back to a different DC voltage to match the batteries. Thus, changing the impedance of the load as seen by the solar panels and preserving more of the output power from the solar panels. With MPPT controllers the solar panels can be connected in strings with higher transfer voltage, so that a smaller wire size is needed and you save on cable cost. Most MPPT controllers are microprocessor controlled. They continuously measure the output from the solar panels and the voltage of the batteries to make needed adjustments. Operating at high frequency in the 20-80 kHz range they have the advantage that they can be designed with high efficiency transformers and small components (Northern Arizona Wind & Sun Inc).

Advanced charge controllers use a three-stage charging process:

- **Bulk Stage** - the charge controller operates in constant current mode, delivering the maximum current to the batteries (Schneider Electric, 2015, pp. 1-4).

- **Absorption Stage** - the charge controller operates in constant voltage mode and the charging current falls gradually as the amp hours are returned to the battery (Schneider Electric, 2015, pp. 1-4).

- **Float Stage** - the voltage of the batteries is held at the float voltage setting with a minimum of charging current. When the battery voltage drops below a recharge voltage setting for some time, a new bulk cycle is initiated (Schneider Electric, 2015, pp. 1-5).

Many charge controllers have a function to equalize the charge level of batteries. Equalization is a deliberate overcharge, designed to return each battery cell to optimum condition by reducing sulfation and stratification of the battery. The equalization charge is generally performed only on flooded, vented lead-acid batteries. Some charge controllers have a circuitry to monitor battery temperature to prevent the batteries from overheating, and have a computer interface for monitoring and control. Low Voltage Disconnect (LVD) continually monitors battery voltage and disconnects the load when a low voltage is sensed. This extends the battery lifetime by preventing over-discharge (Northern Arizona Wind & Sun Inc).

2.5 Inverters

An inverter is an electronic device with the purpose of converting direct current (DC) provided by an external DC source into alternating current (AC). The input voltage, output voltage, frequency, and produced power from the inverter depends on the characteristics and design of the inverter. An inverter can be entirely electronic or a combined electromechanical device. The shape of the delivered sinewave varies with the circuit design of the chosen inverter. How to choose the correct inverter for a system depends on the budget and needed quality for the powered equipment (Gevorkian, 2006, pp. 12-13).

The basic principle of an inverter:

- DC power is delivered to the inverter by the centre tap of the primary winding.
- A switch is rapidly going back and forth, allowing the current to flow back to its source following two alternating paths.
- The alternation of the direct current in the primary winding then produces alternating current in the secondary winding.

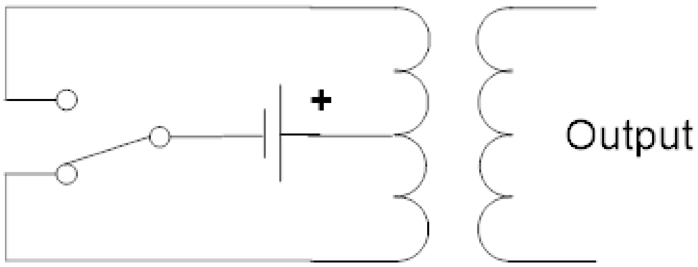

Figure 2.5 - Basic Principle of an Inverter

The simple inverter showed in Figure 2.5 and described above, produces AC power with a square voltage waveform due to its simple off and on function. It is often desirable to achieve a more sinusoidal waveform, as the one we get from the power grid or any AC power supply. To achieve this an inverter with a more complex design can be used, or connect the inverter to an output line-frequency transformer. Capacitors and inductors can also be used to filter the waveform (MpptSolar).

One specific type of inverter is the solar inverter which plays a significant role in an AC photovoltaic system. Whether it is to provide power to the commercial electrical grid, or used in an off-grid electrical system. With the use of a solar inverter in a solar power system, it is permitting the use of AC powered equipment, fed by the DC solar power source (MpptSolar).

The main difference between a power inverter in general and a solar inverter is that the solar inverter must adapt to the variable DC power provided by the solar cells. Due to this, solar power inverters may come with functions like Maximum Power Point Tracking (MPPT) and anti-island protection. Inverters with a MPPT function samples the given output power seen with a Current-Voltage curve from the solar modules. The MPPT`s function is to obtain maximum power at any time during operation based on the energy available. With an anti-island protection, the inverter detects the presence of utility power. If the grid is having a power outage, the solar power system must stop feeding power into the grid for safety reasons (ABB, 2014).

In solar power systems, you can also have use of a solar micro-inverter. A solar micro inverter is designed to operate on a single PV module alone. The advantages with this is the optimization of every single panel, in addition to an independent and improved operation (Enphase Energy).

3 Method

Chapter three gives a thorough explanation of the methods that are used when assessing the electrical systems at the hospital. It includes descriptions on how information was gathered, methods of assessing the electrical system, and the calculations & use of a simulation program for the solar power system.

To achieve the goal of this report, literature available on solar power, project documents, technical reports & drawings of the hospital, tenders from EFO, and technical specifications from suppliers were used. Communication with EFO also proved to be a solid base of information.

The information gathering for this report started with taking part in the Engineers Without Borders project planning meetings in 2016. Here, basic solar power theory was learnt, and requirements for the solar power system were developed. Specific requirements for the site in Sierra Leone was gathered and a power usage profile was developed. This was also a good introduction to the different input data needed for solar power system simulations, with different configurations being simulated in the PVsyst simulation software.

Further information on the different parameters needed for the solar power system simulations are described in Chapter 3.5 PVsyst 6.6.0 Photovoltaic Software Simulation.

With EFO chosen as a local supplier, and the final system configuration decided in January 2017, the collection of the different technical specifications could start. Owners & planning guides from Schneider Electric proved to be a good source of information.
For general solar power theory, the book *“Sustainable Energy System Engineering: the complete green building design resource”* (Gevorkian, 2006) was used. Online resources and solar power design guides were also helpful.

A list of available information from the Engineers Without Borders project phase was compiled by the external tutor for this bachelor thesis. Here information on the solar power system tender from EFO, hospital electrical diagrams, energy consumption profiles, and information on the generators were supplied. An electrical survey report was also made available.

Additional information on the delivered solar power system were supplied by Simon Willans, co-founder of EFO.

3.1 Electrical System

3.1.1 Network Grounding Systems

The different electrical networks that are used to distribute electricity to the consumers have varied layouts. The network categories have different advantages and disadvantages in terms of ground faults & leakage current, electrical hazards, ability to deliver different voltages, etc.

Three different network types are defined in IEC 60364 using the letters T-Terra, N-Neutral, and I-Isolation (International Electrotechnical Commission, 2005, pp. 33-60):

- **TN-network**
  - TN-S: The PE (Protective Earth) and N (Neutral) are separate conductors that are connected only near the power source. The power can be drawn from three phases, giving 400 V to the consumer. The power can also be drawn from three phases and the N-conductor, giving 230 V to the consumer. An example of a TN-S-network is shown in Figure 3.1.
  - TN-C: A combined PEN-conductor fulfils the functions of both a PE-conductor and a N-conductor.
  - TN-C-S: A combined PEN-conductor is drawn from the transformer to the first distribution point. Then the PEN-conductor is split into a separate PE-conductor and a N-conductor.

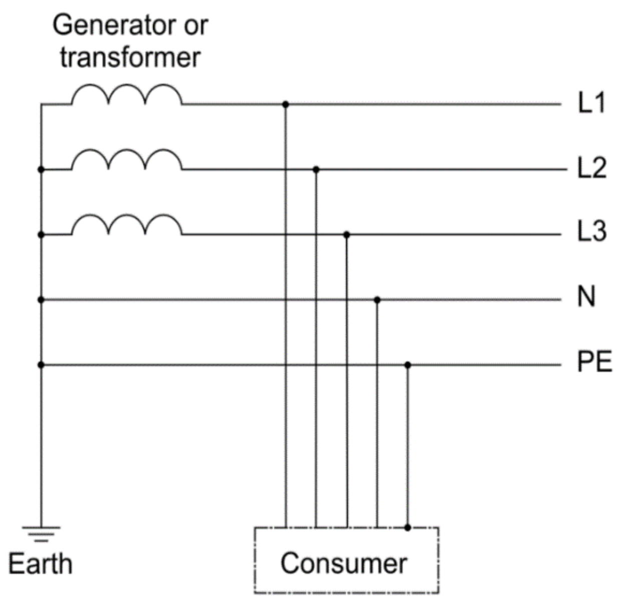

Figure 3.1 - TN-S-network system. Source: Markus Kuhn

- **IT-network**
  The zero-point of the transformer is connected to the Protective Earth, only through a high impedance connection or overvoltage protection. The N-conductor is not used. The power is drawn from three phases, giving 230 V to the consumers. An example of an IT-network is shown in Figure 3.2.

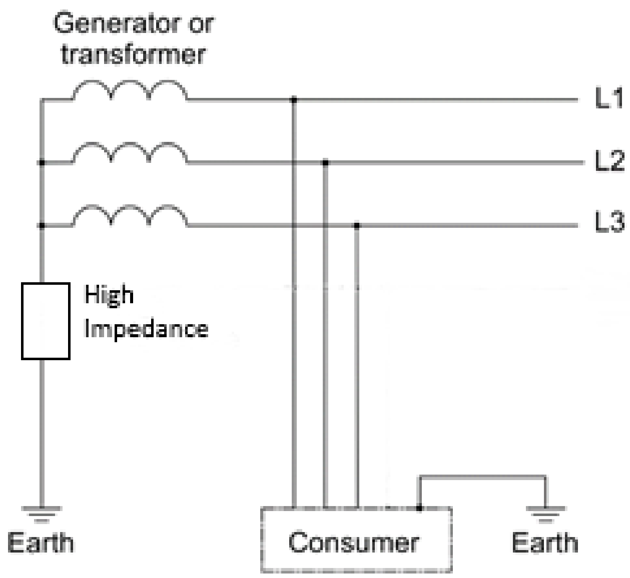

Figure 3.2 - IT-network. Source: Markus Kuhn

- **TT-network**
  The PE-conductor at the consumer is not connected to the Protective Earth of the transformer. The power is drawn from three phases, giving 230 V to the consumer. An example of a TT-network is shown in Figure 3.3.

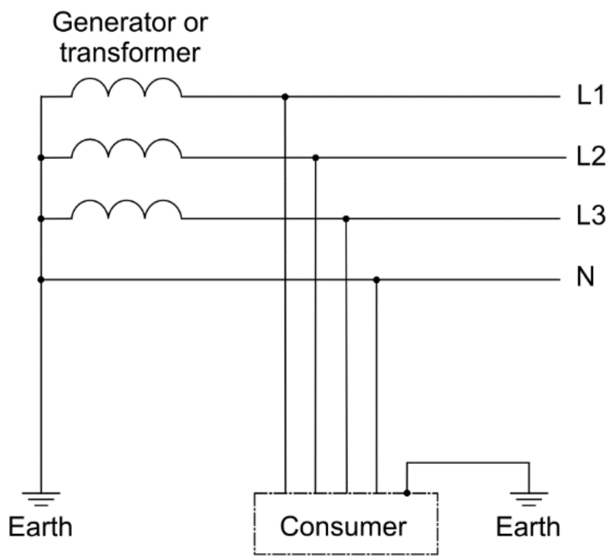

Figure 3.3 - TT-network. Source: Markus Kuhn

Table 3.1 shows the advantages and disadvantages of the different network types.

Table 3.1 - The Different Network Systems

	TN-network	**TT-network**	**IT-network**
Advantages	-High system voltage with both 230 V and 400 V available at the consumer point. -Lower installation cost due to smaller cable size. -Ground faults and leakage current will most likely trip the circuit breaker.	- Reduced interference from connected equipment. -Less electrical hazard due to lower voltage. -No risk if neutral is disconnected.	-Less electrical hazard due to lower voltage. -Ground faults and leakage current will not disconnect the system without a residual-current device. -Smaller ground fault currents.
Disadvantages	-Electrical hazard due to high voltage. -The system is cut off automatically with the first ground fault. -Risk of wrongly connecting 400 V to 230 V equipment. - A risk if neutral is disconnected. 400 V may then power 230 V equipment.	-400 V not available at the consumer point without a transformer. -Higher installation cost due to the need of a larger cable size.	-400 V not available at the consumer point without a transformer. -Higher installation cost due to larger cable size needed. -Can become a TT-network if the overvoltage protection unit is broken.

(Kamel, Chaouachi, & Nagasaka , 2011)

3.1.2 Selectivity

The selectivity in an electrical network system is an important factor to consider in terms of how the network responds to electrical faults. A good selectivity means that only the circuit breaker closest to the fault will cut off the electrical circuit. The fault is then isolated to the local network, and the rest of the electrical system is not influenced.

If the selectivity is inferior, an electrical fault may trigger several circuit breakers at the same time, or it may trigger a circuit breaker further up in the electrical network system. The result is that a larger part of the electrical system is influenced. The worst case is an outage of the whole electrical system (Cadex Electronics Inc, 2016).

For small electrical network systems, the selectivity issue is solved by using circuit breakers with higher break currents and longer release time the further up it is in the network. What level of selectivity that is needed in an electrical network, depends on what the consequences of a sudden power outage has for the users in the network. If a stable and secure power supply is vital, the selectivity must be good (International Electrotechnical Commission, 2005).

3.1.3 Power Capacity

A vital factor to consider in an electrical network system in terms of safety, is how the cables, protective devices, and fuses in the network are sized. The cables must be able to handle the amount of drawn current without overheating. The cables must also be sized so that any short-circuit currents are large enough to trigger the circuit breakers. If the dimension of a long cable is too small, the cables electrical resistance will be high. The short-circuit current in case of an electrical fault will then be too small to trigger the circuit breaker. Protective devices and circuit breakers must be sized according to the need of the consumer, and so that the amount of power does not cause overheating in the cable (International Electrotechnical Commission, 2005).

3.2 Solar Power System Architecture

An important decision when designing a solar power system is to choose what kind of electrical bus architecture to use. A solar power system can be either AC-coupled, DC-coupled, or hybrid-coupled.

- **AC-coupled System** - The DC output from the solar panels is directly converted to AC for use at the consumer. If batteries are used in the system an AC to DC converter must be connected to charge the batteries (shown in Figure 3.4). Advantages with this system includes, that the power provided from the solar panels only have to go through one conversion step, reducing electrical losses. This system is also good if there is a long distance from the solar panels to the main system. When using high voltage AC to transfer the solar power, the size of the transfer cables can be reduced. A disadvantage with this system is that stored power in the batteries must go through more than one step. First a conversion to AC from the solar panels, then a conversion back to DC to be stored in the batteries. When power is needed to be drawn from the batteries, power must be converted back to AC again. This increases electrical losses (Schneider Electric, 2016, pp. 2-2).

- **DC-coupled System** - Output from the solar panels is first converted to the correct DC level, and then connected to charge the batteries. The power is then converted to AC for use at the consumer (shown in Figure 3.4). An advantage with this system is that power that is stored in the batteries only has to go through one conversion step from the solar panels. This reduces electrical losses for the stored power. A disadvantage is that power that is drawn directly from the solar panels to the consumer must go through an extra conversion step. This increases the electrical losses for the used power during sun hours (Schneider Electric, 2016, pp. 2-2).

- **Hybrid-coupled System** – AC-coupling and DC-coupling are used in the same system. This can be useful if the solar panels are located both near and further away from the main system. It can also be useful if consumers have different needs, or the solar power system is retrofitted (Schneider Electric, 2016, pp. 2-2).

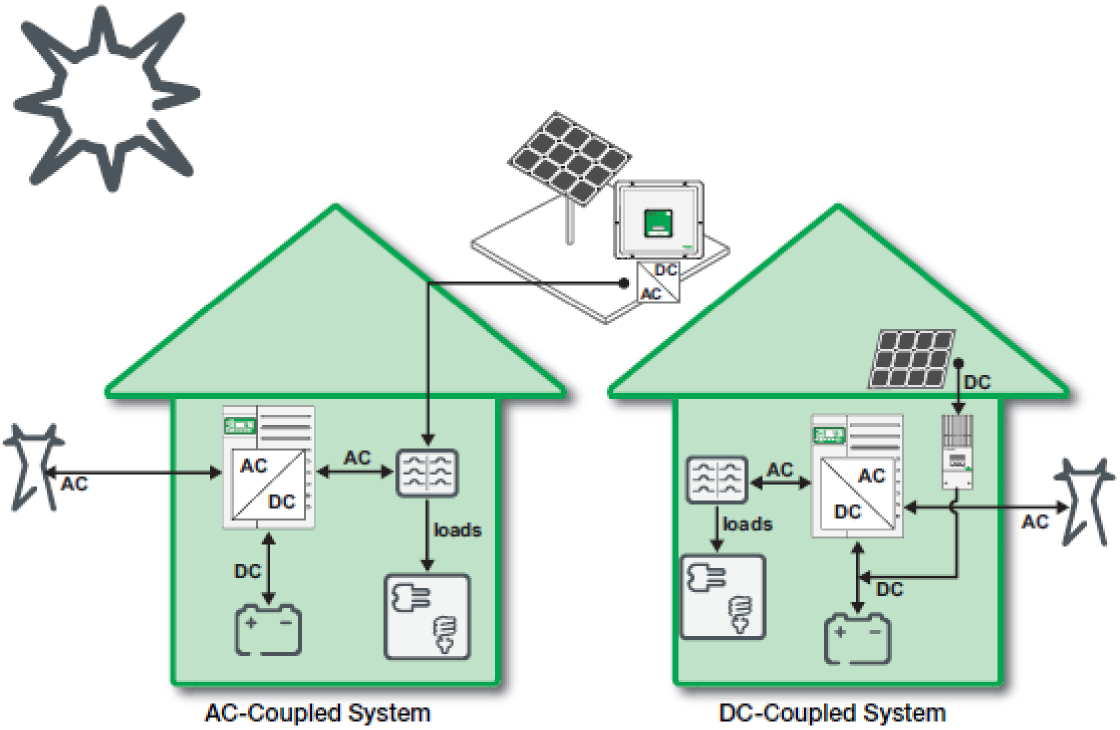

Figure 3.4 - Example of a AC-coupled and a DC-coupled Solar Power System. Source: Schneider Electric

One factor when determining the electrical architecture is the power usage profile. If most of the power is used during sun hours (Figure 3.5), an AC-coupled system can be the best choice. If most of the power is used in the evening or at night (Figure 3.6), a DC-coupled system would be the best choice (Schneider Electric, 2016, pp. 2-5).

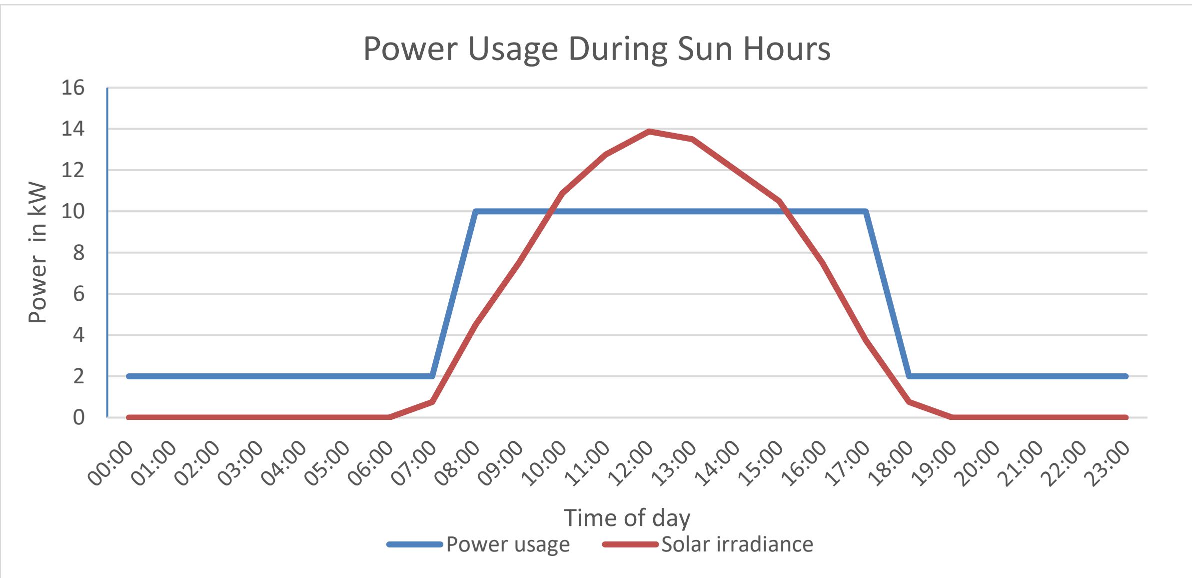

Figure 3.5 - Power Usage During Sun Hours

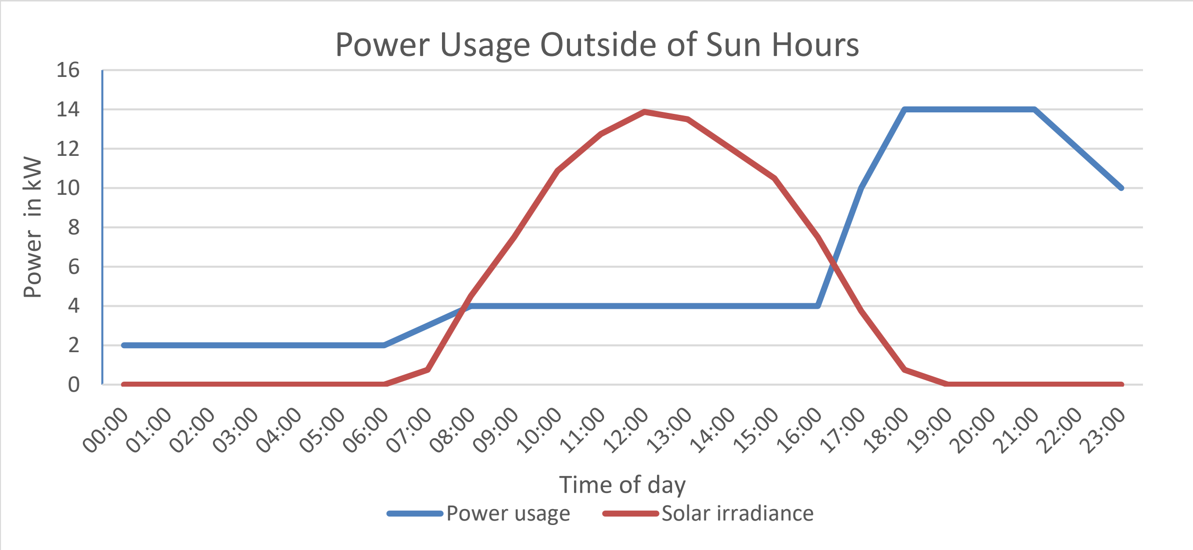

Figure 3.6 - Power Usage Outside of Sun Hours

3.3 Solar Power System Calculations

When calculating a solar power system, the power consumption in the installation, irradiance at the site location, and possible generated energy determines the size of the power system that is needed (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 2). The methods and equations that are used when determining the varied factors will be described further down in this chapter.

3.3.1 Power Consumption

When defining the energy required from the solar power system, an assessment of the connected appliances must be done. The power usage at the hospital in Rotifunk determines the daily energy demand the solar power system must provide. The figures are reached by calculating the power that is needed for the different appliances, multiplied with the number of units. The total hourly power consumption of the installation is then found by the sum of every load operating within every hour.

$$P_{pr.\ load}(W) = P_{pr.appliances}\ (W) \times Number\ of\ Units \tag{1}$$

$$P_{pr.hour}(W) = \sum P_{pr.load\ operating\ within\ the\ hour}(W) \tag{2}$$

When the hourly consumption has been determined, the daily energy demand is found by the sum of every hourly power consumption within 24 hours.

$$E_{total\ pr.day}(Wh) = \sum P_{pr.hour}\ (\mathrm{W}) \tag{3}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 2-4)

3.3.2 PV Array Area

The size of the PV array (the area of solar panels) will determine the amount of energy that can be generated from the absorbed irradiance. The irradiance data used when calculating the power system in Rotifunk was downloaded from the PVsyst program, and the linked Meteonorm database.

With the energy demand determined, the next step is to find the size of the area of solar panels that can absorb enough energy to match the energy demand. The generated energy must be the same or greater than the energy demand.

$$E_{generated}\ (Wh) \geq E_{demand}\ (Wh)$$

To calculate the PV array area, the following equation is used:

$$PV\ Array\ Area\ (m^2) = \frac{E_{load}}{H \times \eta_{pv} \times T_{cell-eff.} \times \eta_{out}} \tag{4}$$

E_{load}= Energy Load (Wh)
H= Solar Irradiance (kWh/m^2)
η_{pv}= The Efficiency of the Solar Panels
$T_{cell-eff.}$ = Cell Temperature Efficiency Correction Factor
η_{out}= Charge Controller Efficiency × Battery Efficiency × Inverter Efficiency × Cable Loss

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 12-15)

3.3.3 Required PV Array Output

The required PV array output can be calculated by dividing the energy demand from the PV array with the peak sun hours (PSH) at the site location. The number of kWh/m^2 pr. day is equal to the number of PSH.

$$Peak\ PV\ Array\ Output\ (W) = \frac{E_{pv\ array}\ (\frac{Wh}{day})}{PHS} \tag{5}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 12)

3.3.4 Derating of the Module Performance

The tolerance of the manufacturer, dirt, debris, and surrounding temperature have an influence on the modules performance. To calculate the cell temperature correction-factor the following equations are used:

$$T_{Cell-eff.}\ (^\circ C) = T_{ave.day}\ (^\circ C) + 25^\circ C \tag{6}$$

Temperature loss is given as:

$$Temperature\ Loss\ (\%) = T_{ave.day}\ (^{\circ}C) \times Temp.Coeff. \tag{7}$$

The temperature coefficient is determined by the cell technology and given by the manufacturer.

The temperature derating factor:

$$T_{derating\ factor} = \frac{100\ \% - Temp.\ Loss\ (\%)}{100\ \%} \tag{8}$$

To adjust the module power, the peak power is multiplied by the temperature derating factor and the dirt derating factor ($\eta_{dirt.corr}$)

$$Module\ Power\ (W) = P_{peak\ power\ module}\ (W) \times T_{derating\ factor} \times \eta_{dirt.corr} \tag{9}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 13-14)

3.3.5 Number of PV Array Modules

When calculating the number of PV modules that are required to meet the energy demand in the installation, the calculated array power is divided with the adjusted module power.

$$Number\ of\ PV\ Array\ Modules = \frac{Required\ PV\ Array\ Power\ (W)}{Module\ Power\ (W)} \tag{10}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 14)

3.3.6 Tilt, Mounting and Solar Shadowing

The tilt of the panels is dependent on the latitude of the location, and is often set to the latitude degree. The performance can be improved by adjusting the angle for summer and winter time. A tilt degree of ± 5 degrees on the latitude is within the desired values (Landau, 2015).

$$Tilt(^{\circ}) = \mp 5\ Degrees\ on\ Latitude \tag{11}$$

3.3.7 Peak Power

If assessing an already sized PV array, it could be useful to see how the array covers the peak power consumption in the installation. The generated energy should be greater than the peak power in the consumption, unless the peak is of little importance and happens rarely.

$$E_{generated}\ (Wh) \geq E_{peak\ power\ consumption}\ (Wh) \tag{12}$$

3.3.8 Capacity Factor

The capacity factor is the ratio between the generated energy over a period of time, and the peak power energy over the same amount of time. It gives an idea on how much energy the solar power system is generating, compared to what it would generate under ideal operating conditions (National Renewable Energy Laboratory, 2014). This can be calculated as:

$$Capacity\ Factor(\%) = \frac{E_{generated}\frac{kWh}{year}}{P_{module\ peak\ power}\ (W) \times 8760\ h} \tag{13}$$

3.3.9 Solar Fraction

The solar fraction shows how much of the energy demand (E_{load}) in the installation that is covered by the generated energy (E_H) from the solar power system. This gives an idea on how the system will perform in terms of providing energy to the consumers in the installation (National Renewable Energy Laboratory, 2014) .

$$Solar\ Fraction\ (\%) = \frac{E_H\ (Wh)}{E_{load}\ (Wh)} \tag{14}$$

3.3.10 Batteries

When calculating the needed capacity from the battery bank, the needed battery storage is determined by the following equation:

$$Battery\ Storage(Wh) = \frac{E_{load}\ (Wh) \times N_C}{DOD \times \eta_{out}} \tag{15}$$

N_c = Days of Autonomy
DOD = Depth of Discharge

The battery capacity is then found by dividing the battery storage with the system voltage:

$$Battery\ Capacity(Ah) = \frac{Battery\ Storage\ (Wh)}{System\ Voltage\ (V)} \tag{16}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 4-7)

3.3.11 Charge Controller

The controllers size should be 25 % more than the arrays short circuit current. It should also be able to handle the arrays open circuit voltage.

The charge controllers expected input current is calculated:

$$Current_{C.C.input}(I) = 1.25 \times\ Number\ of\ Strings\ (pcs) \times PV\ Array_{SC}\ (I) \tag{17}$$

$$Current_{pv\ array\ output}\ (I) \leq\ Max.Current_{C.C,pv\ array\ input}(I) \tag{18}$$

$$Voltage_{pv\ array\ output}\ (V) \leq Max.Voltage_{C.C,pv\ array\ input}(V) \tag{19}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 11)

3.3.12 Inverter

The inverter must be able to cover the following:

- Be capable to supply power to all AC loads in the installation
- Have a sufficient surge capability if having loads in the installation that may cause a surge when turned on.

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 10)

3.4 Solar Power System Configurations

To assess if the delivered solar power system is optimal and to evaluate possible future upgrades, different solar power system configurations was simulated in the PVsyst simulation program.

Simulations of three different solar power system configuration categories was done:

- Simulations for the delivered solar power system using the conservative power usage profile in Appendix C1 (Power Consumption: 137 kWh/day), within the same budget as in EFO`s tender. The number of solar panels, charge controllers and batteries was varied.
- Simulations for a small upgrade using the conservative power usage profile, Power Consumption: 137 kWh/day. A varied number of solar panels, charge controllers, and batteries was added.
- Simulations for a large upgrade using a full power usage profile, as shown in Appendix C2 (Power Consumption: 360 kWh/day). A varied number of solar panels, charge controllers, batteries, and inverters was added.

For simplicity, it was chosen to evaluate different system configurations using the same products as in the delivered solar power system. For upgrade purposes, using the same products would also make the installation easier. It was chosen to use the same DC-coupled system layout, with a battery bank connected to DC charge controllers. A system without any batteries should also have been simulated, but this was not possible with the chosen simulation software.

Price estimates was simplified using a fixed cost of 50 % of the total equipment price for any miscellaneous equipment, freight, and installation cost. This is similar to the miscellaneous costs of the system that are being delivered by EFO. The total estimate was then found by adding the number of solar panels, the number of batteries, the number of chargers, the number of inverters, and the number of Balance of System units (PDP). The sum was then multiplied by a factor of 1.5 for the miscellaneous cost. Additional building construction costs was not considered.

3.4.1 Number of Solar Panels

For the chosen charge controller, the solar panels must be connected in two or more strings when connected to a 48 V battery bank. The maximum charging power at 48 V is 4800 W. Keeping in mind that the efficiency of the charge controller is 96 % at 48 V, the ideal solar panel power size for each charge controller is 5000 W. The chosen solar panel is rated 250 W. Twenty solar panels connected in two strings equals 5000 W, making it the ideal size. Any input power increase exceeding 5000 W would not be utilized in the charge controller, as can be seen in Figure 3.7. It was therefore chosen not to vary the number of solar panels per charge controller for the simulations (Schneider Electric, 2015, pp. A-3).

Figure 3.7 shows the expected output power from the charge controller at different input voltages, and battery voltages.

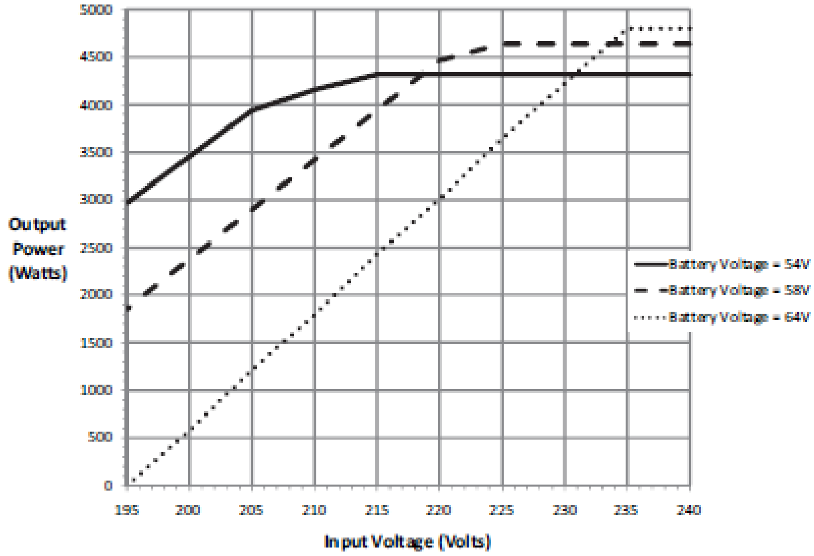

Figure 3.7 - Maximum Expected Output Power, Versus Input Voltage. Source: Schneider Electric

3.4.2 Number of Batteries

The batteries for the chosen charge controller and inverter must be connected in strings providing 48 V. The delivered single battery voltage is 2 V, connected in a string of 24 units. For the simulations, it was chosen to try configurations with a battery bank with less capacity, in addition to configurations with more batteries connected in two strings. With a multi-cluster setup, the batteries must be connected in one or more strings for each cluster (Schneider Electric, 2016, pp. 3-9).

3.4.3 Number of Charge Controllers

The number of charge controllers per inverter is limited by the maximum DC input current of the inverter, or the maximum charging current for the batteries, whichever is lowest. For three XW+ 8548 E Inverters in parallel, the maximum input current is 540 A. The maximum charging current for the Rolls S2-3220GEL Batteries is 600 A. The maximum charging current for the XW MPPT 80 600 Charge Controller is 80 A. It would therefore be possible to connect up to six charge controllers to each of the three inverters (6x80 A=480 A). In the simulations, it was chosen to do simulations of systems with three to six charge controllers per three inverters (Schneider Electric, 2015, pp. A-2).

3.4.4 Number of Inverters

For a three-phase solar power system using Schneider equipment, three XV+ Connect Inverters is needed, each delivering a single-phase. The minimum number of inverters that is needed for the system is therefore three. For more power, up to nine inverters can be added in a multi-cluster setup. Multi cluster setup of more than nine inverters requires that a Schneider Electric Sales Application Engineer pre-validates the configuration during the design and installation phase. For the large upgrade, it was therefore chosen to make simulations for systems with six and nine inverters (Schneider Electric, 2016, pp. 3-7).

Figure 3.8 shows an example of a system with six inverters.

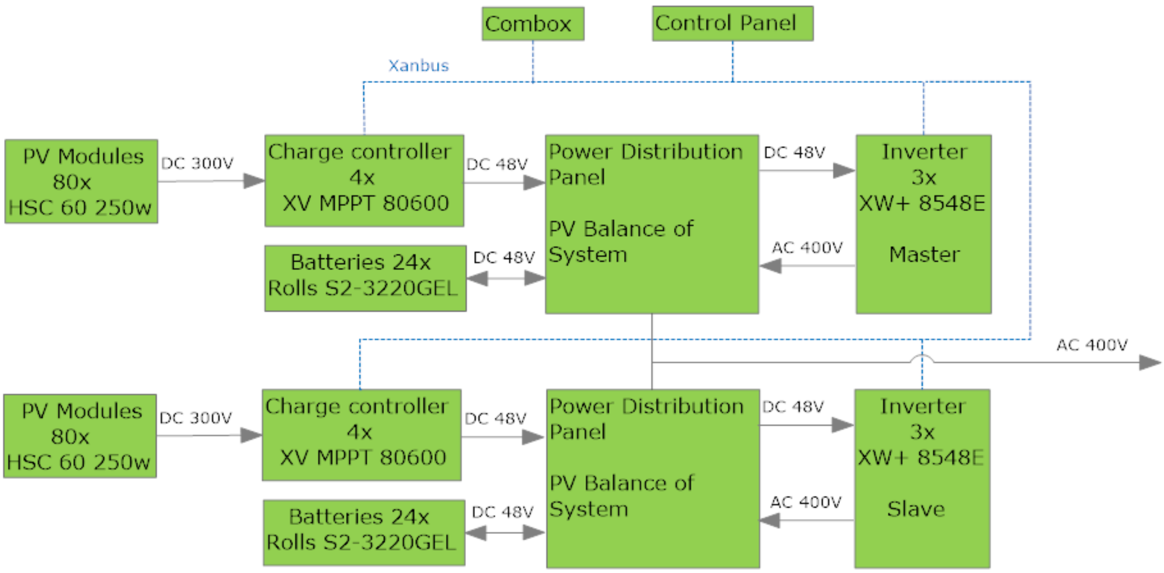

Figure 3.8 - System with Six Inverters and Eight Charge Controllers.

3.5 PVsyst 6.6.0 Photovoltaic Software Simulation

To assess the delivered solar power system, a simulation done in a photovoltaic software program was essential. The program was used to get simulation data of the power provided by the system based on the geographical site, component data and information given by EFO.

3.5.1 Project Designation

Irradiance data sampled from the geographical site of the project in Rotifunk was downloaded from the PVsyst program meteo database.

Geographical site:	Latitude 8.19 ˚N	Longitude -12.66 ˚W
	Altitude 28 m	Albedo 0.20

3.5.2 Input Parameters

- **Orientation**
  The orientation was specified by EFO.

  Tilt: 12 ˚south   Azimuth: -10 ˚south-west

- **User Needs**
  The hourly daily profile used in the simulation is developed by Engineers Without Borders, set to be constant over the year. An extra 7.5 kW load in average was added throughout the day due to the air conditioner in the new battery enclosure. The air conditioners model was not specified, but information of 9000 BTU was given. With the information, 7.5 kW was representative based upon the power consume of other 9000BTU air conditioners (LG Electronics). The simulation program does not by the date of the simulations, support an inverter installed in the simulated power system. As described in the programs help function: *"In the present time, you cannot define an inverter with stand-alone systems: the user's needs are expressed in terms of energy, whatever the DC or AC use. If you have an inverter you should increase the user's needs, to account for its efficiency."* (PVsyst SA) To cover this, an extra 7.5 % was added to the hourly power use to cover for the inverters 92.5 % CEC weighted efficiency, as described in Appendix H4 (Inverter).

  The power usage profile of the hospital was assessed several times within EWB. Different possible hourly loads were discussed based on the equipment usage at the hospital. Due to the limitation of funds, a 20-kW power system was bought.

  In the program default settings for small systems, it is recommended to define a list of appliances with details of their hourly power use. In bigger systems, different options of defining the load profile is available, like the daily profile used in the simulations for the project in Rotifunk (PVsyst SA).

- **System**
  The program has a pre-sizing tool that gives a proposal of required capacity of the battery bank. The PV array power size is created on the defined autonomy, probability of loss of load, and nominal voltage of the battery bank. The Rotifunk project simulations were based on a set power use, and a given power system. This function was therefore used only as a guide to see where a change should be considered if needed.

- **Solar Panels**
  The PVsyst program have a database of different solar panel models and manufactures out on the marked. The panels used in Rotifunk were not already in the database. A new model was made based upon the specification sheet of the HSC 60 Poly Can-Am 250 W Solar Panel. More detailed information about the panel, other than the specification sheet proved to be difficult to find. If in doubt of some parameters, default settings in the program was used.

The program will suggest the number of PV array modules that is the best fit for the chosen battery voltage. In the tender from EFO, 80 units of solar panels were specified.

Note: If direct coupling is used, the PV module voltage ought to match the battery voltage (PVsyst SA).

- **Battery Bank**
  As for the solar panels, the PVsyst program have a database of different battery models and manufactures on the marked. The batteries used in Rotifunk were not already defined in the database. A new model was made based upon the specification sheet for the S2-3220GEL Rolls Battery (Appendix H2) in the program. The operating temperature was set to be 25 ˚C, as specified by EFO.

- **Charge Controller**
  When using solar panels and batteries, a control strategy must be chosen. It can either be through direct coupling, MPPT, or a DC to DC converter. If this is not decided, a universal controller is the recommended choice to start with. This is to prevent being fixated on with specific control conditions early in the simulation process (PVsyst SA).

  The charge controller in Rotifunk is a MPPT controller. The used charge controller model was in PVsyst database, and a new defined model was not necessary.

- **Back-up Settings**
  The charge controller used in Rotifunk is not compatible with a back-up generator, therefore the back-up settings is not relative for the simulations in this project. The charge controller's specification sheet can be found in Appendix H3 (Charge Controller).

  For a different charge controller with generator settings, this application can be used to simulate the coverage of the power consumption with the solar power system, combined with the use of a generator.

- **Detailed Losses**
  The last step in the PV simulation settings is *"Detailed Losses"*. This feature defines the system losses with the chosen models. Array loss parameters are initially set to realistic default values in the PVsyst program. Modifications is only performed during the second step of the study, if needed at all. When the first simulation is done, the losses can be defined according to the equipment used in the simulated solar power system. This includes soiling losses, thermal losses, ohmic wiring losses, module quality losses etc. (PVsyst SA).

When all the above is typed into the PVsyst program it is ready to do a simulation, unless a warning is given. The program will give warnings if the system is not appropriate. If a red warning, the system is not acceptable and changes must be done to be able to do a simulation. Orange warnings is suggestive (PVsyst 6.6.0 Photovoltaic Systems Software, 2017).

3.6 Levelized Cost of Energy

True solar power systems have no fuel costs, but are still capital intensive when being installed. When determining the Levelized Cost of Energy (LCOE), there are three main factors to consider:

- The total cost of the installed solar power system with the electrical equipment and installation.
- The cost of maintenance and replacements of the solar power system during its lifetime.
- The energy generated throughout its lifetime, calculated with the average expected irradiance and age-derating correction factor.

When calculating LCOE, the total cost of the power system during its lifetime, estimated to be 20-30 years is divided on the total generated energy the power system is providing within those years. The estimated lifetime of 20-30 years is an estimate for the system in general, some components may have a shorter lifetime. Batteries for example do usually have a shorter expected lifetime. This varies with the usage profile and manufacturer. Therefore, when assessing the cost of the system, the expected lifetime of every component must be considered to see if extra cost with replacement must be added.

The total cost includes the installation, maintenance, and expected replacements over that period. The total energy is what the system can provide over the same period. Some derating factors due to aging of the system should be considered (Renewable Energy Advisors).

$$LCOE = \frac{Total\ Cost}{Total\ Energy\ (kWh)} \tag{20}$$

4 Results

Chapter four presents the information gathered on the electrical system, the generators, and the solar power system. The chapter also displays the results of the calculations with the delivered power system, and the PVsyst simulation results with the different solar power system configurations.

4.1 Electrical System.

The electrical system at the Hatfield Archer Memorial Hospital is a combination of three-phase and single-phase power, complying with the utilisation category AC 22 A (according to British Standards - BS EN 60947-3). A 20-kVA generator is delivering three-phase, 400 V to the main switches and distribution boards. In addition, a 4-kVA generator is used to power certain sensitive parts of the hospital to reduce use of the 20-kVA generator. The electrical consumers consist largely of air conditioners, fans, fluorescent tubes, LED light bulbs, and medical equipment.

The colour coding used on the cables are in a deprecated British Standard (L1: Red, L2: Yellow, L3: Blue, N: Black). The European Colour Code is used on some power cables, but not according to specification (L1: Brown, L2: Grey, N: Black).

The cables between buildings are mostly in the ground and of good quality, in a good state and can be reused. The present grounding system at the Power House is not acceptable, and should be replaced. A flowchart of the existing electrical system is shown in Figure 4.1. Please see Appendix E2 (Electrical System) for a more detailed technical drawing.

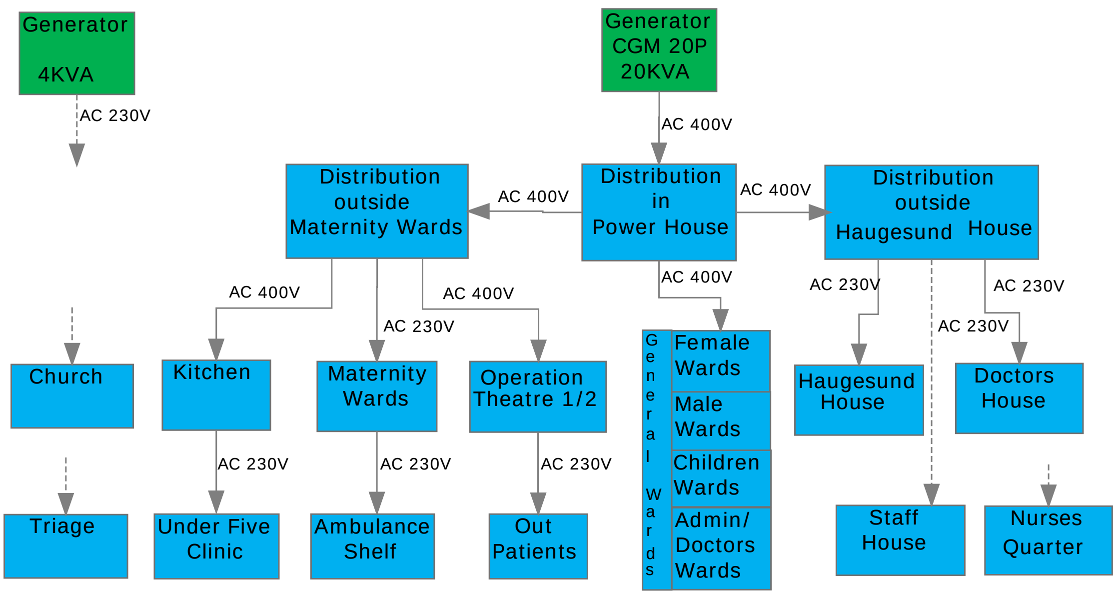

Figure 4.1 - Flowchart of the Existing Electrical System.

4.1.1 Network Grounding System

The network grounding system at the Hatfield Archer Memorial Hospital is a TN-S system, with separate a N and PE conductor, only connected at the power source as shown in Figure 4.2.

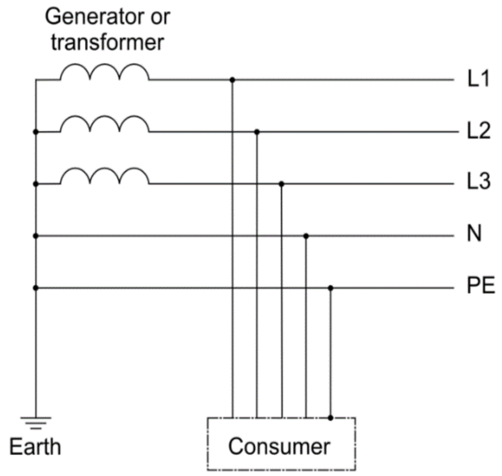

Figure 4.2 - TN-S-network System. Source: Markus Kuhn

4.1.2 Selectivity

Detailed information about the equipment, and what level of selectivity that are present in the hospitals electrical system are not available. The discussions in Chapter 5.1.2 is based on the information that are available on different the size and models of the circuit breakers at the hospital.

4.1.3 Power Capacity

The main switch at the Power House is a 63 A HRC fuse link. The distribution outside of Haugesund House is a 32 A HRC fuse link. Other distribution boards consist largely of consumer units of varied size, connected to 100 A main isolator switches. Information on the different sizes and lengths of the electrical cables at the hospital are not available.

4.1.4 On-site Technical Report Summary

A technical assessment report was made by the EWB team after a field trip to the Hatfield Archer Memorial Hospital in June 2016. The report describes the general state of the electrical system and the electrical installations at the hospital, with suggestions of required modifications.

A local Sierra Leone company, Energy for Opportunities (EFO) was chosen to provide and install the new solar power system. EFO will also inspect in detail the state of the existing electrical installation.

During the trip, a new 4-kVA generator was purchased and installed due to the failure of the 20-kVA generator that have been providing power to the hospital. Parts of the existing electrical system had to be rewired to enable the new generator to supply the system with electricity. This may have to be rewired to the original wiring when a new promised 20-kVA generator is being installed.

The electrical system is a combination of three-phase and single-phase, with consumer units consisting mostly of A/C units, lights, and fans. The installation is assumed to comply with British Standards. The used cable colour coding is both British and European standard. Most of the cables in the ground are of good quality & state, and can be reused.

The following work is needed on the electrical system:

- The ground cable from Haugesund House to the Doctor’s House is damaged by fire, and a replacement is required.
- It is impossible to locate the power cable to the Staff House. This will most likely require a new cable to be installed from the Haugesund House.
- No cables are connected to the Church. New cables are required for it to be powered.
- All of the electrical installations in the Church are in a bad state, and are suggested to be removed and reinstalled properly. They are also to include some light, and sockets suitable for a PA system.
- The Triage is not connected to the rest of the electrical distribution network. It should be connected, either directly to the maternity switchboard, or via the Kitchen/Under-five power cable.
- No electrical installations are present in the Nurse`s quarter. This is suggested to be included in the next installation phase.
- One damaged main switch is replaced, and one damaged main switch must be repaired or replaced.
- The present grounding system is not acceptable, and should be replaced.
- The storage room in the Out-patient Area is to be converted into a laboratory, and should have a possibility to connect an A/C unit.
- The Office in the Out-patient Area is to be converted into a pharmacy, and should have a possibility to connect an A/C unit.
- The two Getinge Autoclaves, SAB 2213 located outside the Operation Theatres requires a permanent connection to the water pipes, in addition to electricity.

The ultrasound equipment was tested, and all appeared to be working except for one in the Operation Theatre Ward.

Please see Appendix G (On-site Technical Report) for more details.

4.2 Solar Power System Architecture

The solar power system at the hospital is DC-coupled, with power from the solar panels being converted to 48 V DC to match the voltage of the batteries. The power is then converted to AC to be used at the consumer units.

A factor when deciding on a AC or DC coupled electrical bus system, is the power usage profile. At the hospital 54 % of the energy demand is outside of sun hours, with the power usage off 137 kW per day. For the 360 kW per day usage profile, the energy demand outside of sun hours is 32 %. This can be seen in Table 4.1 and Figure 4.4.

Table 4.1 - Power Usage During, and Outside of Sun Hours

Time of day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum kWh	%
Power need outside sun hours 137 kWh/day	4	3	3	3	3	3	3	3										8	6	7	7	6	6	5	73	54
Power need inside sun hours 137 kWh/day									7	7	7	7	7	7	7	7	7								64	47
Power need outside sun hours 360 kWh/day	7	6	6	6	6	6	6	6										12	10	11	11	9	9	7	117	32
Power need inside sun hours 360 kWh/day									29	29	29	29	29	29	29	29	11								243	68

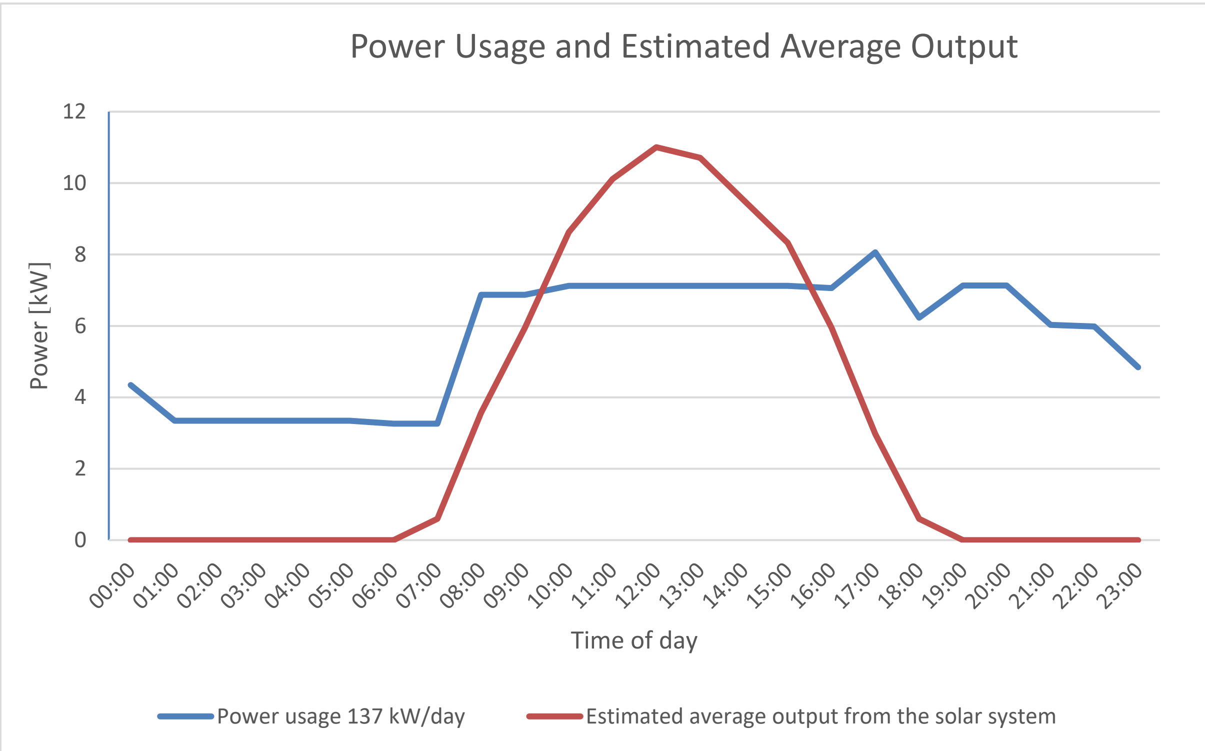

Figure 4.3 - Power Usage and Estimated Output

4.3 Solar Power System Calculations

The solar power system provided to the hospital is being delivered and installed by Energy for Opportunity (EFO) located in Freetown. They were chosen as a total supplier of the solar power system, after several rounds of assessing the offer within the Organisation Haugesund Rotifunk (HR) and Engineers Without Borders – Haugalandet (EWB). In their offer, they are providing a 20-kVA solar power system complete with mounting, battery enclosure and wiring. EFO is also responsible for the transportation of equipment, taxes and required documents[2]. The main components of the offer are shown in Table 4.3.

Table 4.2 - The Main Components in EFO`s Tender

Equipment	Model	Manufacture	Quantity
Solar Panel	HSC 60 Poly Can-AM	Hanwha Solar	80 Units
Charge Controller	XW MPPT 80 600	Schneider Electric	4 Units
Battery	S2-3220GEL	Rolls Battery Engineering	24 Units
Inverter	XW+8548 E	Schneider Electric	3 Units
Control Panel	Conext System Control Panel	Schneider Electric	1 Unit
ComBox	Conext Combox	Schneider Electric	1 Unit

Please see Appendix F (Tender from EFO) for further information.

Figure 4.5 shows a flowchart of the delivered solar power system, together with the generator and how it is connected. Please see Appendix E1 (Solar Power System) for a more detailed technical drawing of the solar power system.

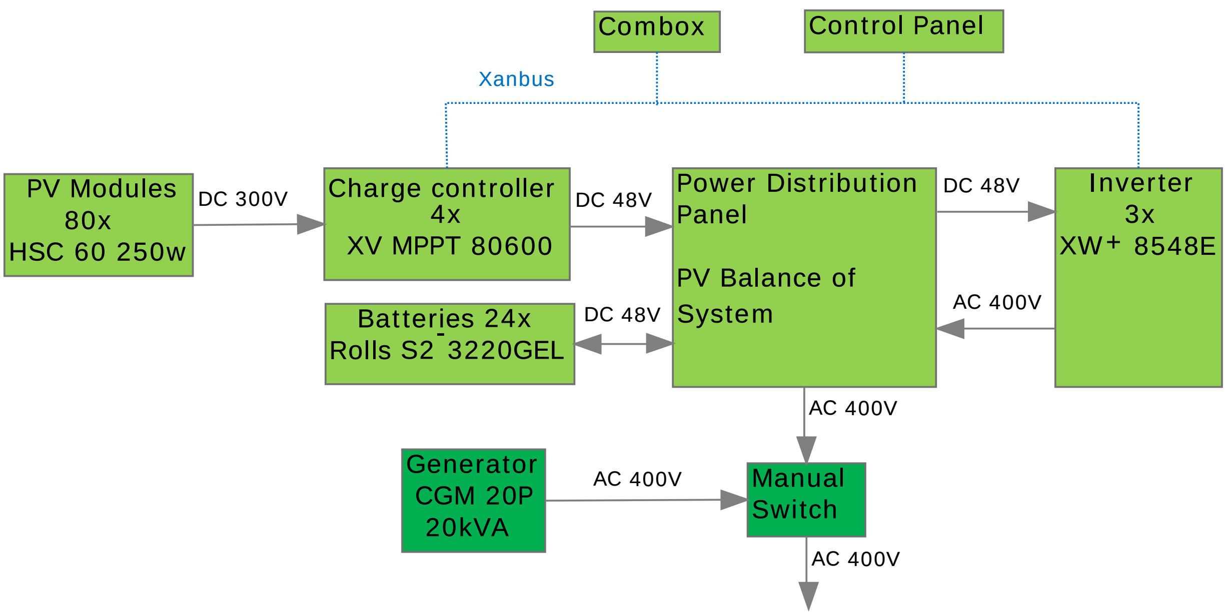

Figure 4.4 - Flowchart of the Delivered Solar Power System.

[2] Information given in the solar power system tender and in e-mail correspondence with EFO, the supplier in Sierra Leone.

4.3.1 Power Consumption

The power consumption used in the assessment and calculations in this report, are based upon an analysis of the hospital power needs done by engineers from EWB. Several assessments were done. In the first stages of the solar power system simulation process different daily profiles were considered. Due to limitations of the delivered system, a simplified profile had to be used giving a daily power consumption of 137 kWh/day (as shown in Table 4.4). Only the use of the most vital electrical equipment in the different sections of the hospital are considered.

Table 4.4 presents a summary of the assessed hourly power consumption at the hospital. The detailed power consumption can be found in Appendix C1 (Power Consumption: 137 kWh/day).

Table 4.3 - Power Consumption Summary

Hour:	Watts:	Hour:	Watts:	Hour:	Watts:	Hour:	Watts:
00:00	4342	06:00	3262	12:00	7124	18:00	6230
01:00	3342	07:00	3262	13:00	7124	19:00	7130
02:00	3342	08:00	6874	14:00	7124	20:00	7130
03:00	3342	09:00	6874	15:00	7124	21:00	6030
04:00	3342	10:00	7124	16:00	7062	22:00	5982
05:00	3342	11:00	7124	17:00	8062	23:00	4842

$$E_{total\ demand} = 136\ 538\ Wh/day$$

The daily profile (Figure 4.6) is set to be constant over the year. The energy demand will most likely vary from each day and by season, but a constant profile simplifies the work when designing the system.

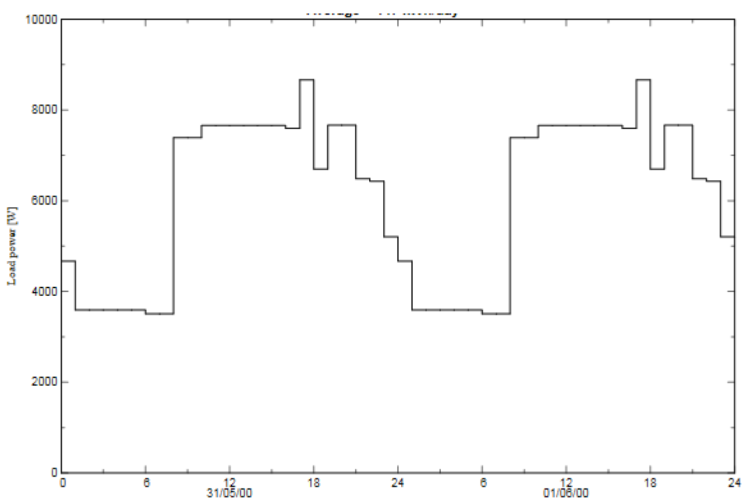

Figure 4.5 - Daily Profile of Energy Usage at the Hospital.

4.3.2 PV Array Area

The delivered solar power system consists of 80 units of the HSC 60 Poly Can-Am Solar Panel. The module is made with a polycrystalline cell technology. Table 4.5 shows the basic data of the HSC 60 Poly Can-Am Solar Panels. Please see Appendix H1 (Solar Panel) for more detailed information.

Table 4.4 - Basic Data of the HSC 60 Poly Can-Am Solar Panels

Power Class	250 W
Modules in Series	10 Units
Modules in Strings	8 Strings
Number of Modules	80 Units
Area	131 m^2
V_{mpp} (20 ^oC)	311 V

The 80 units of solar panels in EFO`s tender gives a total PV Array area of 131 m^2. If calculating the PV array area needed with the power consumption of 137 kWh/day, and irradiance data at Rotifunk, it gives:

$$PV\ Array\ Area\ (m^2) = 336\ m^2 \tag{4}$$

Please see Appendix J (Solar Power System Design Guideline), p.9 for more thorough calculations.

4.3.3 PV Array Output

The 80 units of solar panels give a peak power output of:

$$PV\ Array\ Output_{peak\ power} = 250\ W \times 80\ Units\ of\ Solar\ Panels = 20\ kW$$

The solar power system that is delivered has an already set configuration. If calculating the PV array output based upon the power consumption, system derating factors, and peak sun hours at Rotifunk, it gives a PV array energy demand of:

$$PV\ Array\ Output = 45\ kW \tag{5}$$

Please see Appendix J (Solar Power System Design Guideline), p.11 for a more thorough calculation.

4.3.4 Derating Module Performance

Several factors, like cell temperature and dirt layers have an impact on the performance of the PV module. The 250 W rating of the module is what it performs in ideal conditions. If considering the derating factors of the module, the adjusted output power is expected to be:

$$Module\ Power\ (W) = 205\ W \tag{9}$$

Please see Appendix J (Solar Power System Design Guideline), p.13 for more thorough calculations.

4.3.5 Number of PV Array Modules

The offer from EFO gives a set number of PV modules, at 80 units.

If calculating the required number of modules with the given power consumption, solar irradiance data, and derating factors it gives a required number of:

$$Number\ of\ PV\ Array\ Modules = 239\ Modules \tag{10}$$

Please see Appendix J (Solar Power System Design Guideline), p.14 for more thorough calculations.

4.3.6 Mounting, Tilt and Solar Shadowing

The panels will be mounted on aluminium frames with a tilt and azimuth of [3]:

Tilt: 12 ˚south Azimuth: -10 ˚south-west

4.3.7 Peak Power

The solar power system given in the tender from EFO has a peak power output of 20 kW, this will provide 175.2 MWh/year. The energy demand in the installation has a peak power consumption of 8.06 kW as seen in Appendix A1 (Power Consumption: 137 kWh/day). The generated power should be the same or greater than the peak power consumption.

With the set power system, the area it covers with solar panels is 131 m^2. The maximum power it can provide in July is:

$$E_{max.} = 48 \frac{kWh}{m^2 pr.day} \tag{4}$$

The peak power consumption is found in the daily profile from 16:00 AM to 17:00 AM. The generated energy at that time, based upon the worst irradiance value in July is calculated to be:

$$E_{generated,SPH} = 12\ kW \tag{5}$$

[3] Information given by EFO

$$12\ kW \geq 8.06\ kW\ \ OK! \tag{12}$$

Please see Appendix J (Solar Power System Design Guideline), p.16 for a more thorough calculation.

4.3.8 Capacity Factor

When operating in ideal conditions the delivered power system is providing 175.2 MWh/year. The PVsyst simulation report of the same system gave the generated energy to be 29.28 MWh/year.

This gives a solar capacity factor of:

$$Capacity\ Factor = 17\ \% \tag{13}$$

Please see Appendix J (Solar Power System Design Guideline), p.17 for more thorough calculations.

4.3.9 Solar Fraction

With the PV modules in EFO`s tender and the site global irradiance data that can be found in Appendix D (Solar Irradiance Data at Rotifunk), the maximum solar fraction was calculated.

The global irradiance data of July, the month of lowest irradiance is measured to be 125.2 kWh/m^2.mth. The solar fraction was also calculated for March, the month of highest solar irradiance with a measured irradiance of 186.2 kWh/m^2.mth. The calculation can be found in Appendix C2 (Calculated Solar Fraction), but the results is given as:

Maximum calculated solar fraction for July:

$$Solar\ Fraction\ (\%) = 35\ \% \tag{14}$$

Maximum calculated solar fraction for March:

$$Solar\ Fraction\ (\%) = 52\ \% \tag{14}$$

These calculations are based upon the horizontal irradiance at the site. The PV array will experience more irradiance because of enhancing factors like tilt and albedo. These are included in more advanced equations, and will be considered in the simulation programs results. To be able to interpret the results in the PVsyst report, the solar fraction was calculated with the horizontal values by hand to have some reference figures.

The simulation gave the solar fraction in July to be 39 %, and in March to be 63 %. The average solar fraction throughout the year is given as:

$$Simulated\ Average\ Solar\ Fraction = 54\ \%$$

4.3.10 Batteries

The S2-3220GEL batteries that are being installed have a gel-technology considered to be maintenance free. The manufacture describes the batteries to have low internal resistance that allows quick recharging with less than a 2 % self-discharge rate. The gel batteries perform well with high cycle use, even in challenging operating conditions (Rolls Battery, p. 27).

Table 4.6 shows the basic data of the S2-3220GEL batteries. Please see Appendix H2 (Batteries) for more detailed information.

Table 4.5 - Basic Data of the S2-3220GEL Batteries

Batteries in Series	24 Units
Number of Strings	1 String
Number of Batteries	24 Units
Battery bank Voltage	48 V
Nominal Capacity (C20)	3220 Ah
Total Weight / (per unit)	5400 kg/ (225 kg)
Operating Battery Temp.	25 ˚C

The nominal capacity of the battery bank is estimated to be the same as its C_{20} value of 3220 Ah. The calculated required capacity for the system, as given in Appendix J (Solar Power System Design Guideline), pp.20-23 is:

$$\text{Required } Battery\ Capacity\ (Ah) = 10\ 694\ Ah \tag{15}$$

From this, the hours of autonomy that the installed battery bank of 3220 Ah can provide is:

$$Hours\ of\ Autonomy\ (h) = \frac{24\ h \times 3220\ Ah}{10\ 694\ Ah} = 7\ h$$

4.3.11 Charge Controller

Four MPPT 80 800 charge controllers are being delivered in the offer from EFO. Each can be connected to two strings of solar panels. If four strings of 20 solar panels in series are connected to the charger as first assumed, the total V_{mmp} would be greater than the maximum input voltage of the charger. The total power of the string would also be greater than what the charger is dimensioned for. This determines the configuration of the solar panels to be eight strings of ten solar panels in series, with two strings connected to each charge controller.

The charge controllers are connected and communicates with three XW inverter/charger units in the installation, using the Xanbus Communication Network. To deliver maximum power from the PV array to the battery bank, the charge controllers have an integrated MPPT function. Each charger has an 80 A charge current capability, and adjusts the PV array current to be at a suitable level for the batteries, in addition to a three-stage battery charging function (Schneider Electric, 2015).

Table 4.7 shows the basic electrical data of the charge controller. Please see Appendix H3 (Charge Controller) for more detailed information.

Table 4.6 - Basic Data of the MPPT 80 600 Charge Controller

Manufacturer	Schneider Electric	
Quantity	4 Units	
Technology	MPPT Converter	
Battery Management Control:		
	Charging	54.9/50.2 V
	Discharging	45.5/48.9 V
Max. PV Array Open Circuit Voltage	600 VDC	
Max. Power Point Tracking Range	195 to 550 VDC	
Max. Operating Current	23 A	
Nominal Battery Voltages	24 and 48 VDC	
Charger Regulation Method:	Three Stage (bulk, absorption, float)	
	Two Stage (bulk, absorption)	
	Manual Equalization	

When deciding on a charge controller, the most crucial factors is the maximum limitations of current and voltage for the chosen controller. This has been assessed in in Appendix J (Solar Power System Design Guideline), p.25 giving:

$$Current_{PV\ array\ output}\ (A) \leq\ Max.Current_{C.C.input}\ (A)\ \ OK! \tag{18}$$

$$Voltage_{PV\ array\ output}\ (V) \leq Max.Voltage_{C.C.\ input}(A)\ \ OK! \tag{19}$$

When using a MPPT charge controller like the one used at the Rotifunk, it is important that the PV array output values matches the MPPT operating values. It must also never be greater than the MPPT maximum voltage.

When the cell temperature changes, it affects the output voltage of the module as with the output power. More detailed discussion about this can be found in Appendix J (Solar Power System Design Guideline), p.26.

The maximum open circuit voltage is calculated to be:

$$Max. V_{oc} = 40.5\ V$$

The maximum and minimum number of PV modules the charge controller can be connected to is calculated to be:

$$Max. Number\ of\ Mudules = 12$$

$$Min. Number\ of\ Mudules = 5$$

The charge controller's limits decide the number of solar panels that can be coupled in series or parallel. For the one in Rotifunk, several units were required because of this. The total number of panels must be split into groups of 10 panels × 2 strings per charge controller.

4.3.12 Inverter

Three 6800 W Conext XW+8548 E Inverters is to be delivered by EFO, each providing a single-phase voltage of 230 VAC. The Conext XW is a DC to AC converter with applications for battery charging and an AC transfer switch. This allows connection to an external generator or utility grid, letting AC energy be shared during charging, or passing it directly through to output.

The Xanbus Communication Network works with the charge controllers in the system, always monitoring (Schneider Electric, 2015). There is a maximum limit of four Conext units in a single-phase configuration. When using multiple units, a master inverter will synchronize the operation by the shared network. This means that whenever an AC load is existing, all units will produce power, but share the load. When using the transfer relay, loads from the system will be transferred to the external power source. The battery charger will then be activated. In multi-unit systems of more than three, an AC contactor must be used to manage the AC bus (Schneider Electric, 2015). A contactor is a mechanically operating switch, made to manage a large amount of current.

Table 4.8 shows the basic electrical data of the Conext XW+8548 E Inverter. Please see Appendix H4 (Inverter) for more detailed information.

Table 4.7 - Basic Data of the Conext XW+ 6848 Inverter

Continuous Output Power	6800 W
AC Input Voltage Range	L-L: 160-270VAC (240 V nominal)
AC Input Break	60 A Double-pole
DC Input Voltage	48 VAC
Peak Efficiency	95.7 %
CEC Efficiency	92.5 %
AC Output Current	L-L: 48 A

The most important thing when deciding on an inverter, is that the peak power in the installation must match the maximum output power of the inverter.

Each of the three XW+8548E Inverters used in Rotifunk has a continuous output power of 6000 W at 40 ˚C. The peak power in the installation is calculated to be 8.07 kW. Based upon the inverters ability to share the load equally. This means that the load on each inverter is approximately 2.7 kW.

$$2.7\ kW\ \leq\ 6\ kW\ \ OK!$$

4.3.13 PVsyst Simulation Report Results

A simulation of the 20-kVA solar power system given in the tender form EFO was done in the simulation program from PVsyst Photovoltaic Software. After the simulation, the program gave an orange warning highlighting that the PV array power is strongly undersized. The missing energy must be provided by other means.

Table 4.9 shows a summary of the PV simulation report. Please see Appendix C1 (PVsyst Report) for the full simulation report.

Table 4.8 - Summary of the PV Simulation Report

Available Energy	**29.28 MWh/year**
Specific Prod.	1464 kWh/kWp/year
Used Energy	28.67 Mwh/year
Excess (unused)	0.00 Mwh/year
Performance Ratio PR	75.82 %
Solar Fraction SF	53.51 %
Time Fraction	56.2%
Missing Energy:	
Year	24.91 MWh/year
March	1.698 MWh
July	2.774 MWh

With the used power consumption as given in Appendix A1 (Power Consumption: 137 kWh/day) the average power consumption per hour is given as:

$$Power\ Consumption_{per\ hour}\ (W) = \frac{137\ kWh/day}{24\ h} = 6\ kW$$

If using the missing energy values given in the simulation report for the month of lowest and highest irradiance data, an estimated use of a generator per hour can be calculated.

$$Generator\ Use\ in\ July\ (h) = \frac{89.5\ kWh/day}{6\ kW} = 15\ h$$

$$Generator\ Use\ in\ March\ (h) = \frac{54.8\ kWh/day}{6\ kW} = 9\ h$$

Using the irradiance data and values given in the simulation report, graphs showing the estimated output from the solar power system under different conditions can be developed. Please see Appendix C4 (Power Usage and Estimated Output Table) for more detailed information.

Figure 4.7 shows the estimated average output from the solar power system in March, with the power usage 137 kWh/day.

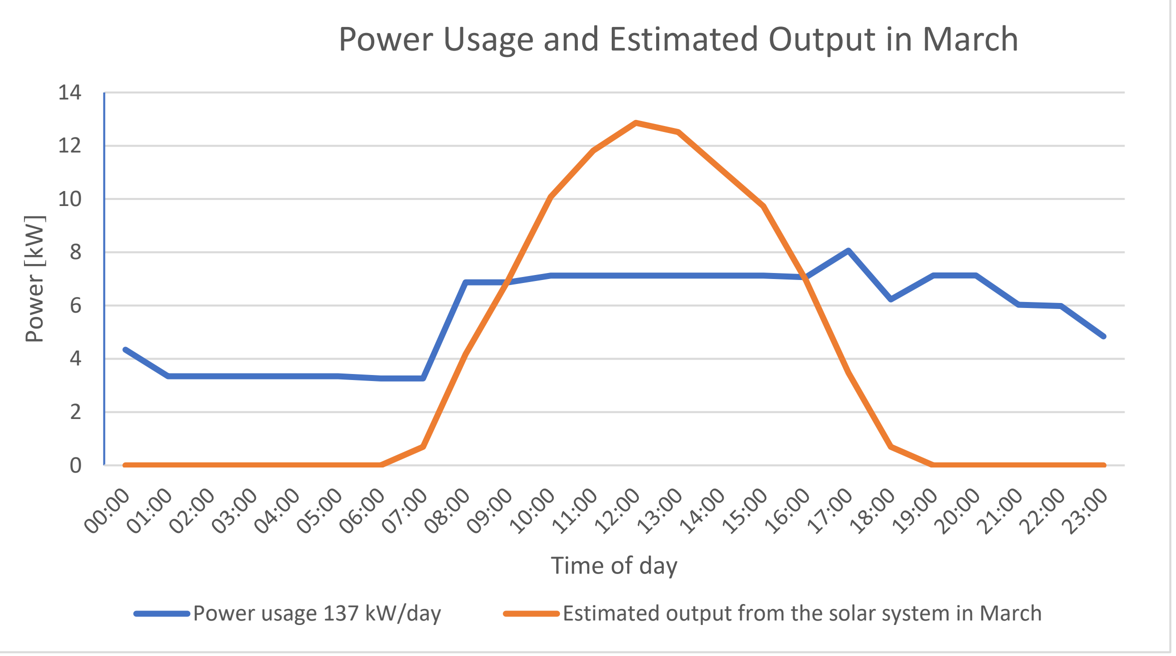

Figure 4.6 - Power Usage and Estimated Output in March

Figure 4.8 shows the estimated average output from the solar power system in July, with the power usage 137 kWh/day.

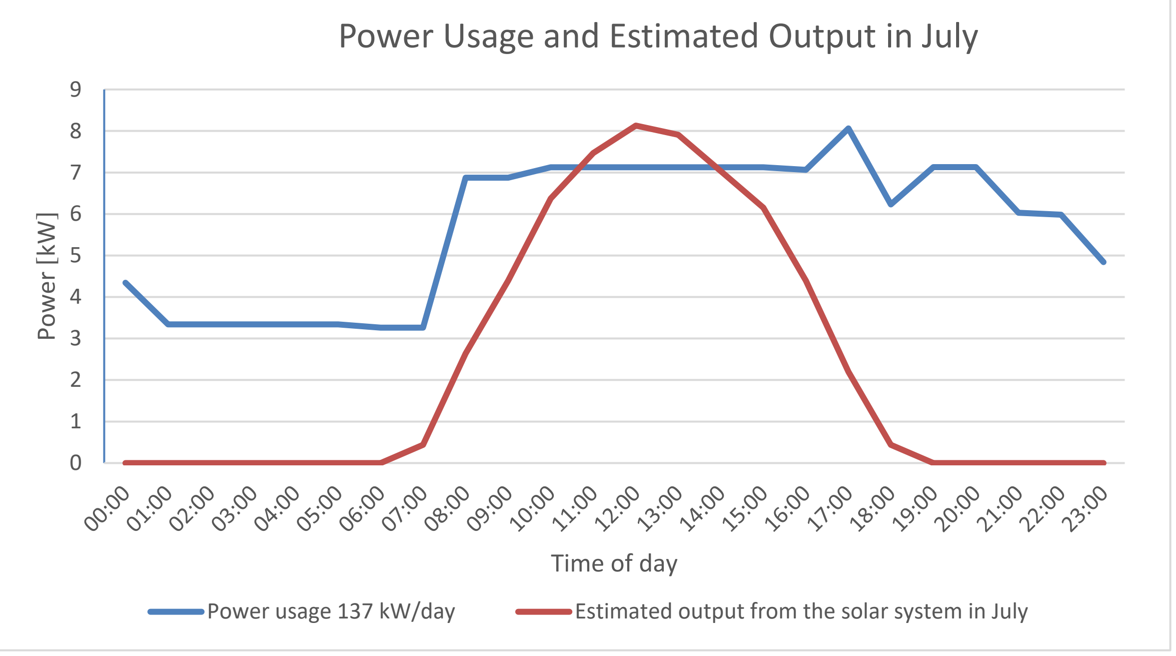

Figure 4.7 - Power Usage and Estimated Output in July

Figure 4.9 shows the estimated average output from the solar power system throughout the year, including battery storage with the power usage of 137 kWh/day. Excess power from the solar power system during the day, is stored in the batteries to be used during the evening and night.

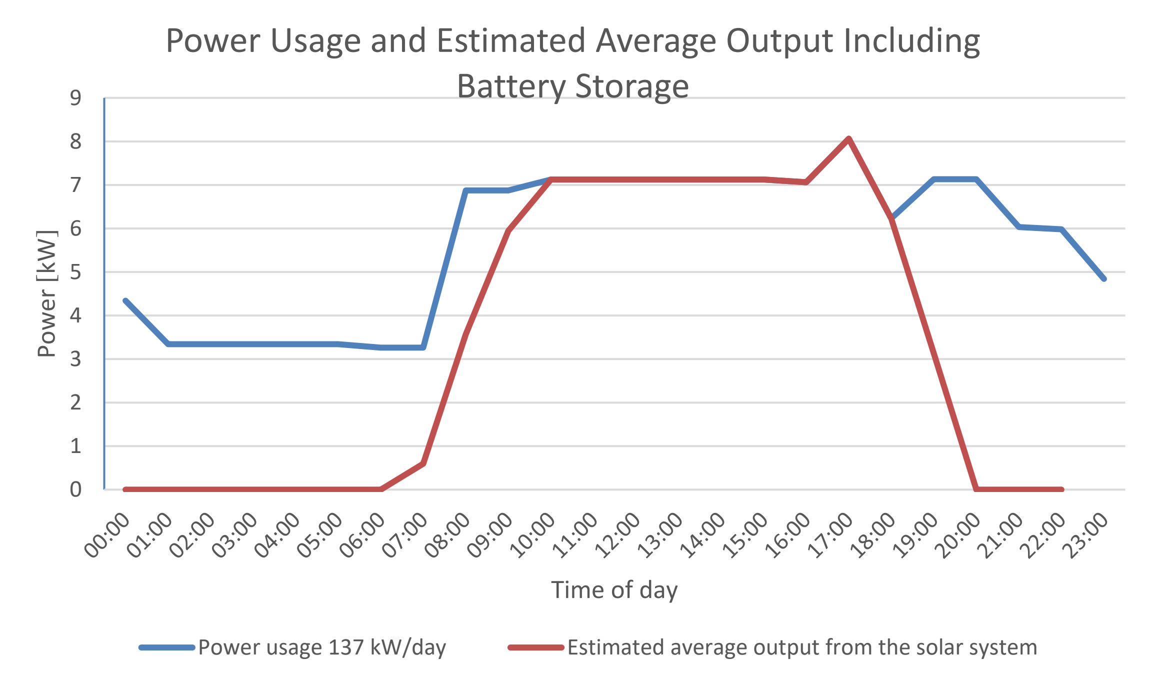

Figure 4.8 - Power Usage and Estimated Output Including Battery Storage.

Figure 4.10 shows the estimated average output from the solar power system throughout the year, including battery storage, and use of the 4-kVA generator. The 4-kVA generator is used to charge the batteries, and to deliver extra power to the system. The estimate is calculated with the power usage of 137 kWh/day.

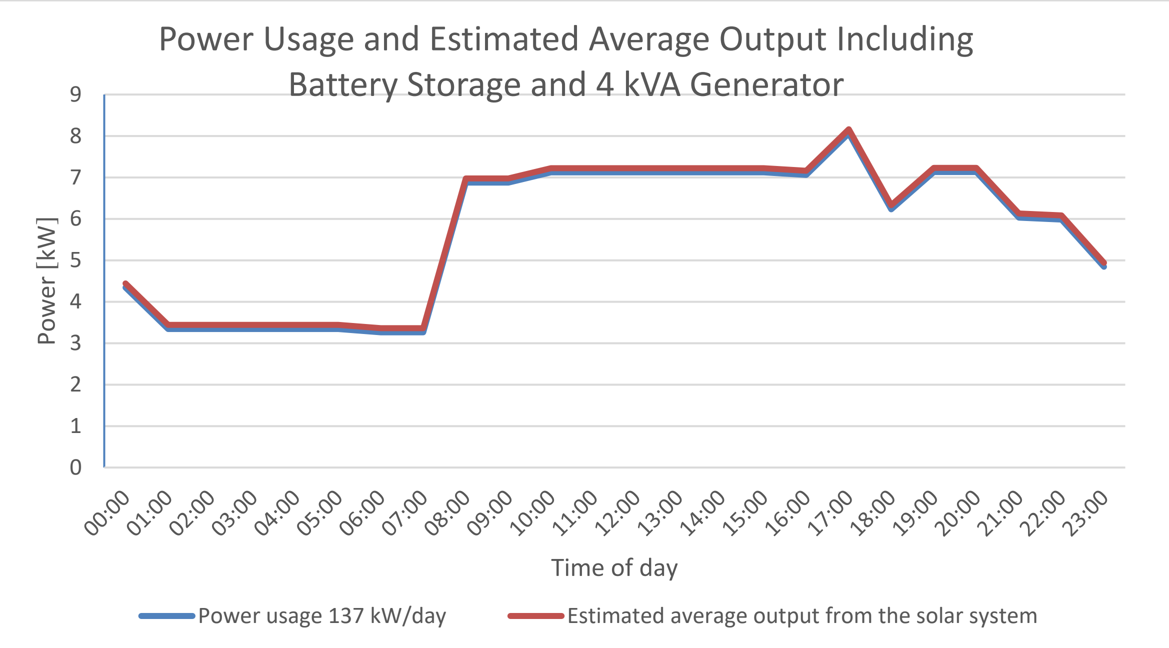

Figure 4.9 - Power Usage and Estimated Output Including Battery Storage and the 4-kVA Generator

Figure 4.11 shows the estimated average output from the solar power system throughout the year, including use of the 4-kVA generator. The output is estimated with the power consumption of 360 kWh/day.

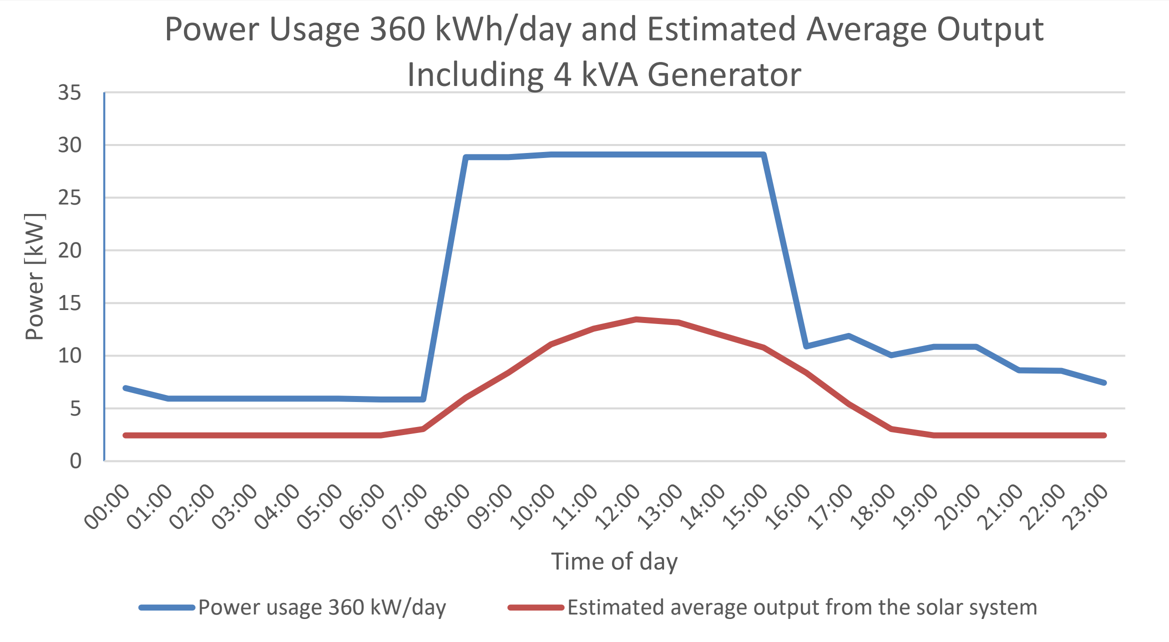

Figure 4.10 - Power Usage of 360 kWh/day and Estimated Output, Including the 4-kVA Generator.

4.4 Solar Power System Configurations

To assess if the delivered solar power system is optimal, and to evaluate possible future upgrades, three different types of solar power system configurations was simulated in the PVsyst simulation program. An explanation on how the configurations was chosen is described in Chapter 3.4. Details of the different configurations are given in Table 4.10.

Table 4.9 - Simulation Data with Different Configurations

Config Number	Solar Panels	Batteries	Charge Controllers	Inverters	kVA Continuous	kVA Peak 30min	Estimated Cost USD	User Need kWh/day
1.1	80	24x3220Ah	4	3	20.4	25.5	104289	137
1.2	120	24x2140Ah	6	3	20.4	25.5	104916	
1.3	60	48x2140Ah	3	3	20.4	25.5	112274	
2.1	80	48x3220Ah	4	3	20.4	25.5	51408	137
2.2	120	24x3220Ah	6	3	20.4	25.5	17871	
2.3	120	48x3220Ah	6	3	20.4	25.5	69279	
3.1	160	48x3220Ah	8	6	40.8	51.0	104289	360
3.2	160	96x3220Ah	8	6	40.8	51.0	207105	
3.3	240	48x3220Ah	12	6	40.8	51.0	140031	
3.4	240	96x3220Ah	12	6	40.8	51.0	242847	
3.5	240	72x3220Ah	12	9	61.2	76.5	208578	
3.6	240	144x3220Ah	12	9	61.2	76.5	362802	
3.7	360	72x3220Ah	18	9	61.2	76.5	258840	
3.8	360	144x3220Ah	18	9	61.2	76.5	406362	

4.4.1 Configurations Within the Same Budget: 137 kWh/day

Figure 4.12 shows the simulation results of the configurations within the same budget as the delivered solar power system from EFO. Configuration 1.1 shows the result for the delivered system. Configuration 1.2 and 1.3 have a varied number of solar panels, batteries and charge controllers. Please see Appendix B (Different Solar Power System Configurations) for more detailed information.

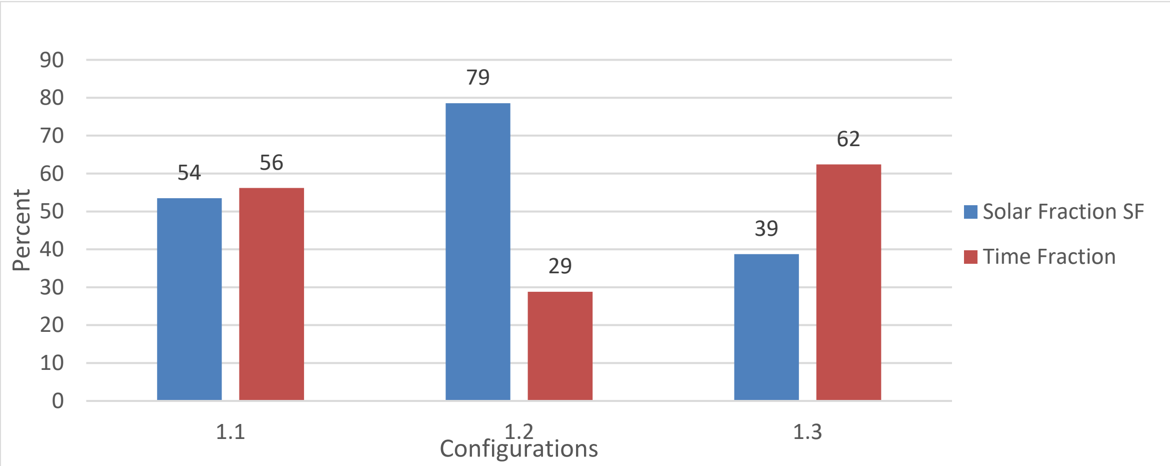

Figure 4.11 - Configurations Within the Same Budget - 137 kWh/day

4.4.2 Configurations for a Small Upgrade: 137 kWh/day

Figure 4.13 shows the simulation results for the configurations with a small upgrade, without increasing the number of inverters. The different configurations have a varied number of solar panels, batteries and charge controllers. Please see Appendix B (Different Solar Power System Configurations) for more detailed information.

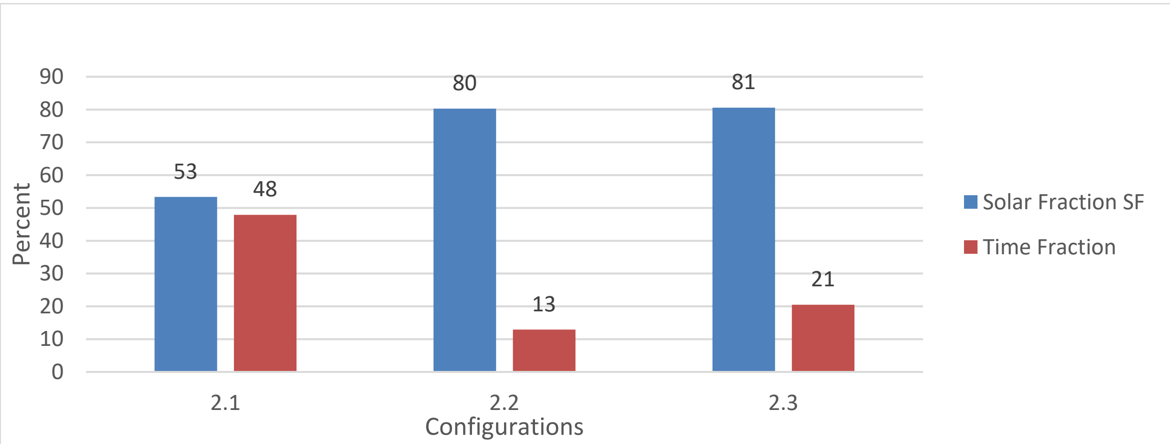

Figure 4.12 - Configurations with a Small Upgrade - 137 kWh/day

4.4.3 Configurations for a Large Upgrade: 360 kWh/day

Figure 4.14 shows the simulation results for configurations with a large upgrade, with an increased number of inverters. The different configurations have a varied number of solar panels, batteries, charge controllers and inverters. Please see Appendix B (Different Solar Power System Configurations) for more detailed information.

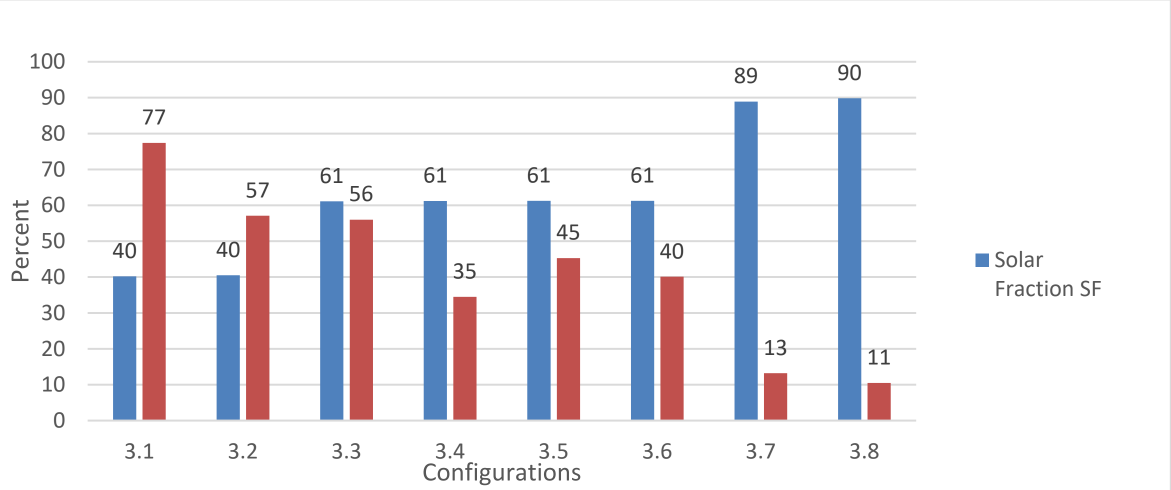

Figure 4.13 - Configurations with a Large Upgrade - 360 kWh/day

4.5 Generators

4.5.1 20-kVA Generator

In early 2017, a new 20-kVA generator (Figure 4.15) was donated to the hospital by the non-profit organisation Global Ministries. The new generator was installed at the same location as the old 20-kVA generator. The temporarily installed 4-kVA generator was removed.

The new generator is a *CGM 20P* model, with a rated output of 16-kVA. The generator has a 5-P, three-phase, 32 A socket, delivering a 400 V TN network. It also has a 3-P, single-phase, 16 A socket for 230 V.

With a full fuel tank of 50 liters, the generator can run for 12.5 hours with 75 % of the load limit, consuming 4 liters of fuel per hour.

Figure 4.14 - New CGM 20-kVA Generator in the Power House

For more technical data please see Appendix H5 (20-kVA Generator).

4.5.2 4-kVA Generator

During the field survey at the hospital in 2016 by EWB, a new 4-kVA diesel generator (Figure 4.16) was purchased. It was installed temporarily to power vital areas of the hospital (the Maternity Ward and one of the Operating Theatres). With the new 20-kVA generator installed in 2017, the 4-kVA generator was disconnected and is now used to power certain sensitive parts of the hospital.

The generator is a *SDMO Diesel 4000 E XL C* model, with a rated output of 2.72 kW. It has two 2P+T power sockets delivering 230 V, 10/16 A. With a full fuel tank of 16 litres, it can run for 17.8 hours with 75 % of the load limit, consuming 0.9 litres of fuel per hour.

Figure 4.15 - 4-kVA SDMO Generator

For more technical data please see Appendix H6 (4-kVA Generator).

4.6 Levelized Cost of Energy

The total cost of the installed solar power system with the used equipment and installation costs is given as[4]:

$$Total\ Contract\ Price = \$\ 124\ 962\ USD$$

The cost of maintenance of the solar power system during a lifetime of 20 years is estimated to be approximately 5 % of the total contract price.

$$Maintainence\ Cost = Estimated\ to\ be\ 5\ \%\ of\ Total\ Contract\ Price$$

$$Maintainence\ Cost = 124\ 926\ USD \times 0.05 = \$\ 6246\ USD$$

In addition to general maintenance, some solar power system components do not have an expected lifetime of 20-years. Therefore, extra costs due to replacements of components must be considered.

Rolls Batteries gives the following information on the expected lifetime of their batteries This can also be found in Appendix H2 (Batteries).

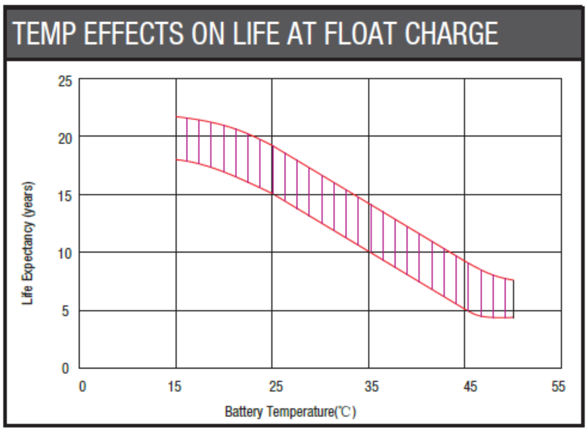

Figure 4.16 - Temperature Effect on Life at Float Charge. Source: Rolls Batteries

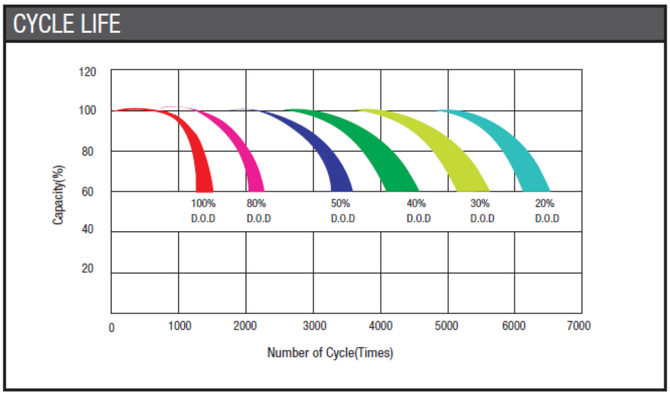

Figure 4.17 - Cycle Life of S2-3220GEL Batteries. Source: Rolls Batteries

4 Information given in the contract between the Sierra Leone Annual Conference of the United Methodist Church and Energy for Opportunity.

The battery enclosure has an air conditioner installed and the batteries surrounding temperature will be 20 ˚C. Seen in Figure 4.17, this gives an expected lifetime of approximately 17 years. The cycle life however (shown in Figure 4.18) with a DOD of 35 %, indicates an expected lifetime of around 5000 cycles. If calculating with one cycle pr. day, this gives a lifetime of approximately 13.7 years. Therefore, it will be reasonable to assume the cost of replacing one battery bank must be included in the total system cost.

$$Replacement\ of\ Battery\ Pack = \$\ 34\ 272\ USD$$

Note: The price of the new battery bank is estimated from the tender from EFO in 2017.

The energy generated throughout its lifetime is calculated with the average expected irradiance and derating percentage of the solar panels. The simulation report calculates the available energy to be 29.28 MWh/year.

Hanwha Solar Panels have a performance warranty of:

- The peak power performance at STC will not be reduced to less than 97 % within the first year.
- The maximum annual power decline is no greater than 0.7 % between the second to the twenty-fourth year

(Hanwha SolarOne, 2012)

Considering this, the minimum available energy over 20 years will be:

$$Min. Avaliable\ Energy = 561.08\ MWh/year$$

Please see Appendix C3 (Calculated Energy Over 20 Years) for more thorough calculations.

The levelized cost of energy for the solar power system in EFO`s tender is then calculated to be:

$$LCOE = \frac{165482.1\ USD}{561078.226\ kWh} = 0.30\frac{USD}{kWh} \tag{20}$$

5 Discussion

In chapter five, the electrical system, the solar power system, the generators and the solar power system configurations are discussed. Any flaws discovered in the result chapter is being brought to light, in addition to assessments of any needed improvements or replacements.

5.1 Electrical System

The field survey done by Engineers Without Borders in 2016, found that the electrical system at the hospital is in an overall good state. It did however uncover several shortcomings and faults that need rectifying. The shortcomings and faults are described in Appendix G (On-site Technical Report), and in the On-site Technical Report Summary in Chapter 4.1.4

EFO has been given the task of addressing the most pressing faults. A new status on the electrical system will be completed in a field survey in 2017. The status on the generators are discussed in Chapter 5.5. The solar power system is discussed in Chapter 5.3

5.1.1 Network Grounding System

The electrical network at the Hatfield Archer Memorial Hospital is a 400 V, TN-S system. It may be argued if a IT-network system would have been more suitable because of its reliability as an electrical system. Installing an IT-network however, would be an expensive rebuilding. A more cost-effective upgrade could be to install an UPS in the system. This would give a more reliable power supply to the connected medical equipment.

A new main grounding system is to be installed at the hospital. A proper grounding system is vital to avoid electrical hazards. A thorough investigation of the whole grounding system should be done to secure a safe electrical system.

5.1.2 Selectivity

Due to limited information on the electrical system, a complete assessment of selectivity cannot be done. Based on the information available, it can be argued the system has some selectivity in place. The consumer circuit breakers have a shorter break time, and lower trip current than the HRC fuse link further up in the electrical network. Therefore, an overcurrent in an electric consumer should not trip the main fuses.

For better selectivity, a system of this small size should ideally have a main distribution board, distributing power to all the different houses and wards with separate circuit breakers. As how the system is connected now, a fault which trips the circuit breaker outside of the Maternity Ward would leave the Kitchen, the Maternity Ward, the Operation Theatre, the Under-five Clinic, the Ambulance Shelf, and the Out-patients Area without power. Rewiring the system to have a main distribution board will require a large investment.

5.1.3 Power Capacity

With the repairs and upgrades suggested in Appendix G (On-site Technical Report), the electrical system should be able to cover the present system requirements. The main distribution circuit breakers can handle loads up to 43.6 kW ($400\ V\ x\ 63\ A\ x\ \sqrt{3}$). With peak power usage estimated to be 31.3 kW (Power Consumption: 360 kWh/day), this would theoretically leave room for 39 % future increase in the power usage. A possible limitation for future upgrade is the 32 A fuses outside of the Maternity Ward. These can only handle loads up to 22.2 kW ($400\ V\ x\ 32\ A\ x\ \sqrt{3}$). The offices and wards connected to this distribution are also the most energy intensive, and future upgrades may be too large for the current network.

5.1.4 Electrical Wiring Code

The present electrical system is assumed to comply with the utilization category AC 22 A (according to British standards - BS EN 60947-3). The new solar power system is said to comply with the US NEC code[5]. For safety reasons, it would be preferable that the system complies with one code only, due to the risk of electrical connection mistakes and hazards. However, since the solar power system is installed in one building only and connected through a manual switch, this may not pose a problem.

For hospital environments, special provisions are present in electrical utilization codes to increase safety. These are made to avoid problems with earthing faults, and secure a stable power delivery to medical equipment. Provisions are also made to avoid electrical hazards and problems with static electricity. It would be a good idea to investigate what kind of measures that are in place at the Hatfield Archer Memorial Hospital. The next step will be to decide on cost-effective upgrades to meet the electrical codes for hospitals.

5.1.5 Energy Conservation

For an off-grid power system, it is vital to minimize the power use as much as possible due to limitations of the provided power. A good deal of power could be saved if the equipment were changed to more energy efficient products (shown in Table 5.2).

Table 5.1 Estimated Saved Power, Based on the Power Consumption of 360 kWh/day

	Number of Items	Total Power Use per Day	Estimated Power Reduction	Estimated Saved Power per Day	Estimated Cost of Replacement
Lights	64x36 W	9.6 kWh	50 %	4.8 kWh	64 × $ 100
Air Condition	12	262.4 kWh	20 %	52.5 kWh	12 × $ 2000
Fans	30	38.8 kWh	20 %	7.8kWh	30 × $ 200
Refrigerator	7	24 kWh	20 %	4.8 kWh	7 × $ 500
Sum				69.8 kWh	$ 39 900

Note: The power reduction and cost of replacement are calculated using estimated values. They are not based on any industry standard.

[5] Information given by EFO

The results indicate the saved cost per kWh to be $ 571 USD. This is similar to what it would cost to increase the output from the solar power system, as described in Chapter 4.4. The Solar Power System Config # 2.2 has an installation cost of $ 446 USD per added kWh. The Solar Power System Config # 3.7 has a cost of $ 921 USD per added kWh.

5.1.6 Future Upgrades

The hospital has expressed a desire to have 110 V available for use with possible donated equipment. A 110 V system could be implemented with a 230 V / 110 V transformer in the Power House, or in the building where a 110 V system is needed. A possible danger when having two systems of different voltage available, is the risk of connecting 110 V equipment to a 230 V socket. This can result in damage of the equipment, or in worst case fire. The risk could be minimized if all 110 V devices was connected to the network through a permanent connection.

If available funds, a good idea could be to upgrade the entire electrical system to increase the selectivity and electrical safety. The system should also be upgraded to handle probable increased power needs in the future. Any buildings missing electrical network should also be included in the upgrade.

5.2 Solar Power System Architecture

Since the solar power system at the hospital is DC-coupled, the stored energy in the batteries will have less electrical losses than they would have if the system was AC-coupled. Correspondingly, energy that are used instantly and not stored in the batteries, will have more electrical losses than what they would have if the system was AC-coupled. Looking at the 137 kW per day power usage profile for the hospital where 54 % of the energy is needed outside of sun hours, a DC-coupled system could be the best choice. Since the power usage is very uncertain, a AC-coupled system could also be a good choice. If looking at the 360 kW per day power usage profile, where 68 % of the power is needed during sun hours, a AC-coupled system is the better choice. If the solar power system is to be upgraded to cover the 360 kW per day power usage, the upgrade could be made using an AC coupled system. This would make the entire system a so-called hybrid system.

5.3 Solar Power System Calculations

The 20-kW solar power system that is now being installed at the hospital have a set generated peak power, this gives certain limitations of energy coverage to the hospital. In Chapter 4.3, the results of the provided power system, and the calculated values based on the power consumption in Appendix A1 (Power Consumption: 137 kWh/day) is shown. The results discovered some diversity in what is provided, shown in the simulation report, and the values that are required with the calculations done by hand. The calculations done by hand is expected to be less accurate, due to the simplified equations that are used when calculating with horizontal irradiance. The calculations however, gives some reference figures to discuss when assessing the power system. The differences that was discovered in the various calculations, and possible solar power system weaknesses are discussed further down in this chapter.

5.3.1 Power Consumption

As mentioned in Chapter 4.3.1, a power consumption of 137 kWh/day is used in the calculations in this report. The power consumption is thoroughly assessed, and only the most essential loads is considered. The hospital does have more loads connected to its electrical installation, which is displayed in Appendix A2 (Power Consumption: 360 kWh/day). Experience also shows that even more loads are believed to be connected in the future. If all possible loads are considered, the 20-kWh power system is not providing enough power. Cuts weighting only the most vital application must be done, and a strict use of the power system should be defined to ensure no overload of the system.

The size of the delivered power system is limited due to the money available, and is what the funds available today could afford to provide. This means that after the first stage of providing a solar power system to the hospital, only the most essential loads can be powered by the system. Further expansion can be considered when additional funds have been provided.

5.3.2 PV Array Area

As shown in Chapter 4.3.2, the area covered with the solar power system in EFO`s tender is:

$$PV\ Array\ Area\ (m^2) = 131\ m^2$$

The calculated required PV array area is:

$$Required\ PV\ Array\ Area\ (m^2) = 336\ m^2 \tag{4}$$

When assessing the PV array area based on the installed system by EFO, and the calculated required area, it gives a missing PV array area of:

$$Missing\ PV\ Array\ Area\ (m^2) = (336 - 131)\ m^2 = 205\ m^2$$

This means that with the solar irradiance data for Rotifunk measured in July, the missing area that needs to be covered to be able to absorb enough energy for the assessed energy demand is 205 m^2.

5.3.3 Required PV Array Output

The power system in EFO`s tender, as shown in Chapter 4.3.3 gives a peak power output of:

$$PV\ Array\ Output_{peak\ power} = 20\ kW$$

The calculated required PV Array Output based on the same data, gives an output of:

$$PV\ Array\ Output = 45\ kW \tag{5}$$

Again, this shows that the installed solar power system is missing solar power panels to provide enough energy for the power consumption at the hospital.

5.3.4 Derating of The Modules Performance

When assessing the PV module with the factors that have an impact on the performance, the adjusted output power of the 250 W Hanwha Solar Panel is calculated to be:

$$Module\ Power\ (W) = 205\ W \tag{9}$$

This value is used when calculating the number of missing PV modules in the installation. If the derating factors did not need to be considered, the missing number of PV modules could be found directly from the missing PV array area. Since derating factors have an impact, the missing numbers will be given by the calculated number of PV array modules, based upon the power consumption. The number of modules is discussed in Chapter 5.3.5.

5.3.5 Numbers of PV Array Modules

As shown in Chapter 4.3.5, the installed power system from EFO has a set number of 80 PV modules.

If calculating the required number of PV modules, it gives:

$$Number\ of\ PV\ Modules = 239\ Modules \tag{10}$$

This makes the missing number of PV modules to be:

$$Missing\ Number\ of\ PV\ \ Modules = (239 - 80)\ Modules = 159\ Modules$$

This shows that the power system that is installed are missing, roughly calculated with the horizontal irradiance values, 159 modules to provide enough energy for the assessed power consumption.

5.3.6 Mounting, Tilt and Solar Shadowing

The mounting and location of the solar panels are vital in terms of the absorbed irradiance from the sun. In the Rotifunk Project the tilt is set by EFO to be approximately 12˚ south. It was also mentioned that the panels would be facing south-west due to the landscape at the installation site. Tilt and solar shadowing is discussed further in Appendix J (Solar Power System Design Guideline), pp. 14-15, but the tilt is in general adapted to the latitude of the location.

For the solar panels in Rotifunk:

$$Tilt(^{\circ}) = \ \mp 5\ Degrees\ on\ Latitude \tag{11}$$

$$3.19^{\circ} \leq 12^{\circ}\ south\ \ \leq 13.19^{\circ}\quad OK! \tag{11}$$

Solar shadowing is a crucial factor to consider when looking at the location and mounting of the solar panels. EFO has given very little information on how this is solved other than the 10 ˚ facing south-west.

In Rotifunk, a fixed grounded mounting for the solar panels is the chosen solution by EFO. Other mounting solutions that could have been used as discussed in Appendix J (Solar Power System Design Guideline), p.15 are:

- **Rooftops or Integrated on Buildings**: To use the rooftops or having panels integrated on buildings could be a good choice if the ground space is limited. The roofs pitch and direction must be ideal for this to be an appropriate choice.

- **Solar Tracking Ground Mounting**: The PV panels are moving and following the suns orbit with the help of solar trackers. This can give an increased irradiance absorption of 50 % during Summer time, and 30 % during Winter time. Solar tracking equipment however, is expensive and require more maintenance

(Gevorkian, 2006, pp. 57-62).

5.3.7 Peak Power

As seen in Chapter 4.3.7, the installed solar power system generates enough energy to provide for the peak power consumption at the hospital in Rotifunk. If the system did not provide enough energy, it would be necessary to look at the usage profile, the size of the peak power, and how often it appeared to determine if the system should be designed differently. If calculating a power system to provide for a power peak of little importance, the total cost of the solar power system could be more than needed for the intended use.

5.3.8 Capacity Factor

The capacity factor showed in Chapter 4.3.8 gives:

$$Capacity\ Factor = 17\ \% \tag{13}$$

Typically, the capacity factor for solar power systems range from 10 % to 25 % with a fixed mounting and tilt. The weighted capacity factor in average for projects in Africa is approximately 22 % (IRENA - International Renewable Energy Agency , 2015, p. 92). This shows that the capacity factor for the installation in Rotifunk is a bit lower than would have been expected. The capacity factor is the ratio between the generated energy over a period of time, and the peak power energy over the same amount of time. This shows that measures should be done to increase the generated power. For example, as mentioned above a greater PV array area would provide more energy.

5.3.9 Solar Fraction

The solar fraction is how much of the energy demand in the installation that is covered by the generated energy from the solar power system. This gives the wanted value of the solar fraction to be as high as possible for the installation. In the Rotifunk project (showed in Chapter 4.3.13) the simulated solar fraction was given as:

$$Simulated\ Average\ Solar\ Fraction = 54\ \%$$

This means that only 54 % of the energy demand is being covered by the solar power system in average. Energy must be provided by other means, in this case using a generator. As mentioned before, measures to increase the solar fraction should be considered to lower the needed use of the generator.

5.3.10 Batteries

The batteries in a solar power system make up approximately 50 % of the total cost. An assessment of the necessity of a battery back-up is consequently vital to determine the funds needed to install the power system.

After determining the hourly power consumption, it will be useful to look at the user profile to determine back-up requirements. In the daily usage profile in Rotifunk as showed in Figure 4.6, the main power usage is during the day when solar irradiance is present. The power consumption at night is in general quite low with an average usage of 3 kW. This raises the point of discussion, regarding if it would be better to install a solar power system without any batteries. During the day, the PV array would provide power directly to the installation, only using a small generator to provide for the power needed at night.

When discussing the energy needs within the project work group from EWB, a set autonomy of one day was chosen due to battery costs. To maintain a constant power-level, the required days of autonomy should be based upon the average number of consecutive days without sun throughout a year at the location.

If not including batteries in the system, the money that are saved could have been used to expand the PV array. This could prove to be beneficial if the power use is at its greatest during sun hours. However, a back-up generator is then required to be used during the rainy season and cloudy weather. The hospital does already have a 20-kVA generator installed that will be connected to the system by a switch. Further discussion on the usage of the generator can be found in Chapter 5.5.

The maximum depth of discharge used in the calculations is 35 %, set from the manufactures proposal of a DOD between 20 – 50 % for an off-grid power system. With the given power consumption, the required battery capacity calculated in Appendix J (Solar Power System Design Guideline), pp.20-23 is:

$$Battery\ Capacity = 10\ 694\ Ah \tag{16}$$

This means the calculated minimum battery capacity must be 10 694 Ah to obtain 1 day of autonomy.

The S2-3220GEL batteries in EFO`s tender has a C_{20} value of 3220 Ah. With the given energy demand, the missing capacity that is necessary to obtain the desired autonomy is:

$$Missing\ Battery\ Capacity = (10\ 694 - 3220)\ Ah = 7474\ Ah$$

Based upon the calculations, the capacity of the batteries in EFO`s tender is not sufficient to cover one day of autonomy. As mentioned earlier, the desired autonomy is decided after evaluating the funds available and the necessity of constant power.

The hours of autonomy with the given calculations of the provided power system and energy demand is:

$$Hours\ of\ Autonomy = 7\ Hours$$

This means that if using the roughly calculated value of battery capacity with the C_{20} value of the batteries, the battery bank that are installed is only providing 30 % of the requested autonomy.

5.3.11 Charge Controller

The four charge controllers that are used in Rotifunk are suitable for the intended use, as showed in Chapter 4.3.11. The charge controllers do have some limitations:

$$Current_{PV\ array\ output}(A) \leq Max.Current_{C.C.input}(A) \tag{18}$$

The maximum and minimum number of PV modules the charge controller can be connected to each string:

$$Max.Number\ of\ Mudules = 12$$

$$Min.Number\ of\ Mudules = 5$$

This means that if the system is to be expanded, a new assessment of the installation, the number of PV modules, and the need for more charge controllers must be done.

5.3.12 Inverter

The three inverters that is used in Rotifunk are suitable for the intended use, as showed in Chapter 4.3.12. The inverters do have some limitations as mentioned in Chapter 3.3.12:

The inverters must be able to:

- Be capable to supply power to all AC loads in the installation
- Have a sufficient surge capability if having loads in the installation that may cause a surge when turned on.

There is also a limit of four inverter units in a single-phase configuration, which may also require extra equipment like distribution panels or contactors. This means that if the system is to be expanded, a new assessment of the of installation and the need for more inverters must be done. The new number of required inverters must then be assessed to see if there is any need for extra equipment.

There has been some discussion if it would be more suitable for each of the three inverters to provide three-phases. This could have made the system less vulnerable for inverter failure, and make it possible to prioritize load so that the most sensitive equipment would be powered even with failures in the system. However, due to the varying usage of all phases, it is necessary to use separate inverters linked through the Xanbus Communication Network to provide the needed three-phase solution (Schneider Electric, 2015).

5.3.13 PVsyst Simulation Report Results

The simulation report gave that the PV array power of the installed solar power system in Rotifunk is strongly undersized based on the power consumption of 137 kWh/day. The solar fraction shows that only half of the energy demand is covered.

A calculation was done to estimate the daily need of a generator with an hourly usage, giving:

$$Generator\ Use\ in\ July\ (h) = 15\ Hours$$

$$Generator\ Use\ in\ March\ (h) = 9\ Hours$$

This means that since the installed power system is too small to cover the assessed power consumption, the generators at the hospital must still be used to provide enough energy.

5.4 Solar Power System Configurations

To further assess if the delivered solar power system is optimal, and to evaluate possible future upgrades, different solar power system configurations were simulated in the PVsyst simulation program.

Please see Chapter 3.4 for a deliberation on the different configurations, and Chapter 4.4 for the results.

5.4.1 Configurations Within the Same Budget: 137 kWh/day

As expected from the results, increasing the number of solar panels also increases the available energy & solar fraction, and decreases the time fraction. This means that more of the power that is needed from the system is available. The results suggest that a decrease of the battery capacity could have been accepted, resulting in a decrease in autonomy for the system. A system with less battery capacity, and more solar panels could have been a more desirable choice. With an increased solar fraction of more than 25 %, the system would probably need to run the back-up generator less. The results however, also show that increasing the number of solar panels to over 120 modules and with a battery capacity of 2140 Ah, would not prove to be cost effective due to unused power.

5.4.2 Configurations for a Small Upgrade: 137 kWh/day

Again, the results show that an increase in number of solar panels is a cost-effective way of also increasing the energy delivered by the system. Increasing the number of solar panels by 50 % results in a 27 % increase in solar fraction, and a decrease in time fraction by 43 %.

The results also show that increasing the size of batteries, without increasing the number of solar panels has no effect on the solar fraction. Depending on the extra battery capacity, a small decrease in time fraction may be seen. If the battery capacity is increased too much without adding any solar panels, the time fraction actually increases. This means that the system delivers the needed energy less of the time.

5.4.3 Configurations for a Large Upgrade: 360 kWh/day

With the large upgrade, the results show that the configurations with 160 solar panels gives a solar fraction of approximately 40 %. The configuration with 240 solar panels gives a solar fraction of around 61 %, and the configuration with 360 solar panels gives a solar fraction of around 89 %. The most cost effective upgrade is configuration # 3.3, with 240 solar panels and 48 batteries. This upgrade comes in at a cost of $ 2392 USD per added MWh/year in available energy. With a solar fraction of 61 %, and a time fraction of 56 %, it gives roughly the same performance as what the delivered solar power system from EFO gives with the power consumption of 137 kWh/day.

Configuration # 3.7, having 360 solar panels and 72 batteries is closer to the ideal system with a solar fraction of 89 %, and a time fraction of 13 %. The installation cost per added MWh/year of available energy is $ 2520 USD. From the results, it can be concluded that adding more panels of more than 360 would not be very cost effective since there would be more unused power.

If looking at the battery capacity, the results show that increasing the capacity without adding any solar panels has no effect on the solar fraction, and only a small effect on the time fraction. The only reason to install more battery capacity would be to increase the autonomy of the system during long periods of cloudy weather, or if more power is used during the evening or at night.

5.5 Generators

5.5.1 20-kVA Generator

The 20-kVA generator can be connected to the hospitals electrical system in two different ways:

- Connected as an emergency back-up generator with a switch to change between solar power and generator power (shown in Figure 5.1). The generator would then be used when the solar power system is not able to deliver enough power to the hospital, or when the solar power system is out of service.

- Connected to the inverters as an integrated part of the solar power system. (shown in Figure 5.2). The generator would then be used to deliver extra power to the hospital when it is needed, and to assist the solar power system in charging the batteries.

Advantages with connecting the generator as a back-up generator, include that all the power from the generator will be utilized when the generator is running, and the hospital will also have a complete back-up if the solar power system is out of service.

A drawback is that the generator cannot be connected to the hospital at the same time as the solar power system to increase power output. Another drawback is that if the generator is connected by a manual switch without automatic start, the hospital will experience a short power outage when the changeover is made. Power outage may also happen if the alarm for low battery in the solar power system is not detected. To avoid any problems with power outage, the hospital could install a small UPS in the system for the most sensitive equipment.

Advantages with connecting the 20- kVA generator as an integrated part of the solar power system, include that the generator could be utilized to deliver more power to the hospital, and deliver extra charging power. This would make it possible to use more power at the hospital, without depleting energy storage. This could enable the use of air conditioners that are installed.

Drawbacks with this connection method, include that it would consume a lot of fuel, and less power from the generator would be utilized when it is running. The inverters can only handle up to 230 V input from a generator, making the effective output from the generator: 20 kVA ÷ $\sqrt{3}$ =11.5 kVA. To utilize more of the power, a transformer could be installed to convert the output voltage of the generator from 400 V to 230 V. This would be an expensive solution since a transformer of this size, capable of 20 kVA is expensive.

Another drawback is that the hospital will not have a complete back-up solution if the solar power system is out of service, without rewiring the system. Running the generator continuously would also require a lot of supervision and maintenance.

Both solutions could be installed with an automatic generator start, avoiding the need for a manual start-up. A potential risk with this, is that if the maintenance schedule for the generator is neglected, the generator could be damaged when started automatically.

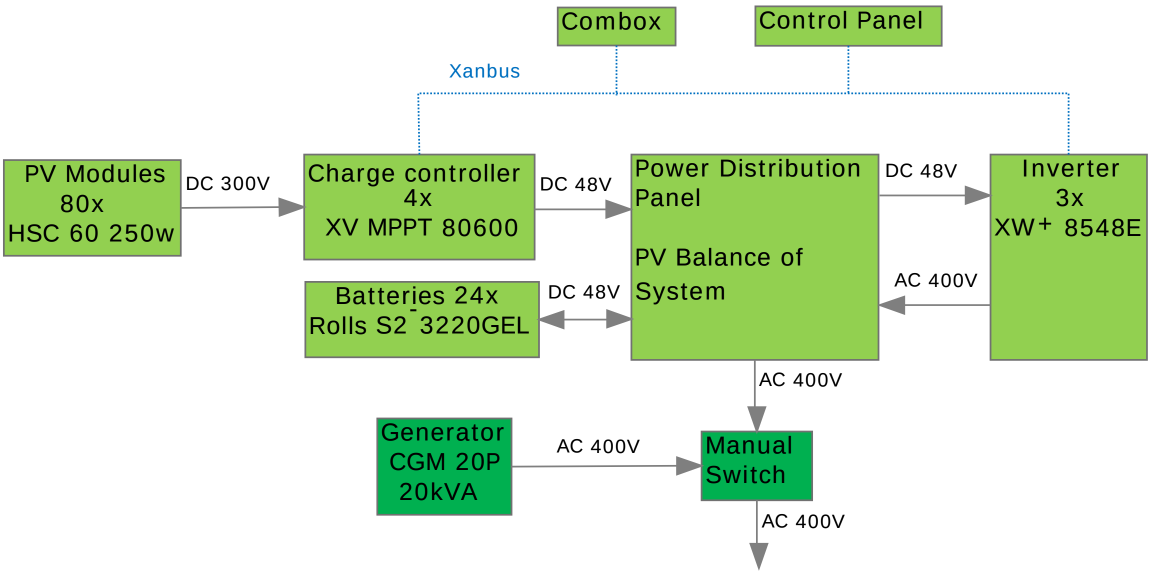

Figure 5.1 - Example with a Back-up Generator

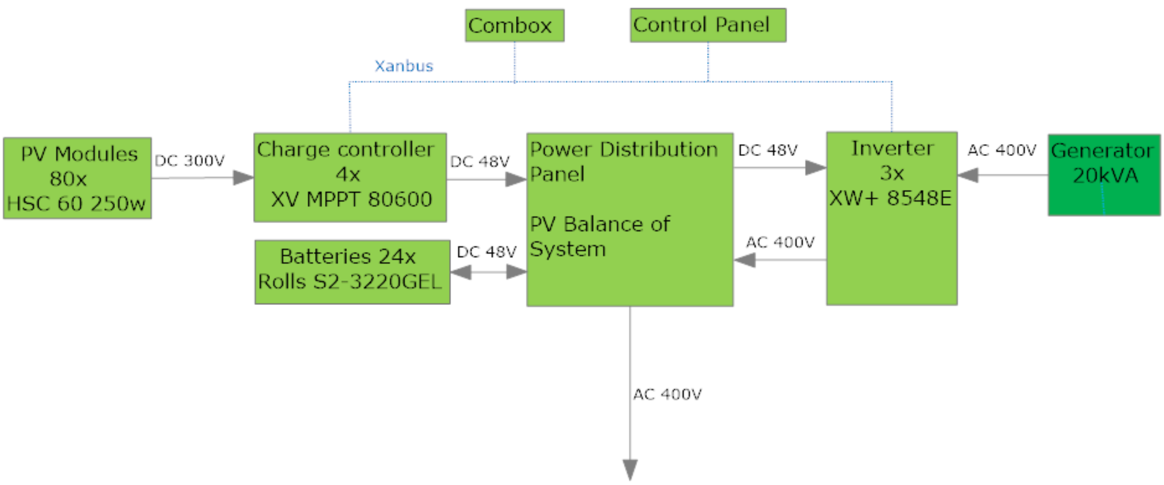

Figure 5.2 - Example with an Integrated Generator

5.5.2 4-kVA Generator

The 4-kVA generator could be connected in two different ways:

- Connected to power certain sensitive parts of the hospital, as it is being used now. This would ease the load on the solar power system, and reduce the need to run the 20-kVA generator.
- Connected to an inverter as an integrated part of the solar power system. The generator would then be used to deliver extra power to the hospital when needed, and to assist the solar power system in charging the batteries

Advantages with connecting the generator to power certain sensitive parts of the hospital, include that it is a flexible solution and the generator could be used where it is needed. It would also reduce the need to run the 20-kVA generator, and save on energy costs. A possible drawback is that running the generator continuously would require a lot of supervision and maintenance.

Advantages with connecting the 4-kVA generator as an integrated part of the solar power system, include that the generator could be utilized to deliver more power to the hospital, and deliver extra charging power. This would make it possible to use more power at the hospital without depleting energy storage. Running at 75 % of full power, the generator could deliver 2.55 kW of extra power to the hospital (3.4 kW x 0.75), consuming 0.75 litres of fuel per hour, or 270 litres per month. A possible drawback is the same as for the first solution. Running the generator continuously would require a lot of supervision and maintenance.

Regardless of the chosen solution for both generators, a maintenance schedule must be implemented to make sure the generators are working properly when they are needed.

5.6 Levelized Cost of Energy

When installing a solar power system, the levelized cost of energy will give knowledge if the system will prove to be profitable or not. Usually this is determined with the LCOE to be less than the electricity tariff. In Rotifunk, connecting to the power grid is not an option. The calculation does however give a cost result to review when determining other options.

The calculation of the LCOE for the delivered power system in Rotifunk can be found in Chapter 4.6. The assessment gave a LCOE of:

$$LCOE = 0.30\frac{USD}{kWh} \tag{20}$$

From Figure 5.18 in IRENA`s cost study of solar power system from 2014 (Renewable Power Generation Cost in 2014, p. 96), the expected LCOE for countries in Africa lays between 0.13 to 0.28 USD/kWh. This shows that the LCOE for the solar power system in Rotifunk is a bit high. With the rural location of the installation however, the LCOE is within what could have been expected.

An alternative could be using the 20-kVA generator that is already installed as the main power source. The diesel price in Sierra Leone is 0.49 USD/l by the 10th April 2017[6]. From the specifications of the 20-kVA generator, it consumes 2.9 l/h when operating at 50 %. That gives a total energy of 240 kWh/day, if used in 24 hours.

$$LCOE_{generator} = \frac{34{,}104\ USD}{240\ kWh} = 0.14\frac{USD}{kWh} \tag{20}$$

This is a rough calculation of the LCOE with use of the generator under ideal conditions. Maintenance, expected lifetime, and frequent stops in operation due to refilling of fuel has not been considered. The main issue when using generators in Sierra Leone is the reliability of accessible fuel, something that has proven to be difficult at the hospital. The generator also requires extra maintenance. Therefore, using a generator as the only power source has proved not to be acceptable.

[6] http://www.globalpetrolprices.com/Sierra-Leone/diesel_prices/

6 Conclusion

After assessing the ongoing project at the Hatfield Archer Memorial Hospital, we have the following conclusions on the delivered solar power system, and the existing electrical system. Included are also recommendations and views on future upgrades.

- The size of the solar power system is not sufficient to deliver the power that is needed at the hospital. Even with the conservative power usage of 137 kWh/day, the 20-kVA generator will have to be run in average 15 hours per day in July, the month of lowest irradiance. In March, the month of highest irradiance, the generator will have to be run in average 9 hours per day.
- The number of solar panels is too small to be able to charge the batteries fully throughout the year. With the number of solar panels, the battery capacity could have been reduced. Having a large battery bank however, is an advantage if the system is to be expanded.
- The capacity of the battery bank is enough to provide 7 hours of autonomy if fully charged.
- The 20-kVA generator should be used as a back-up generator to power the hospital when the solar power system is not able to deliver enough power.
- The 4-kVA generator should be connected to the solar power system to help charge the batteries, and deliver extra power to the hospital.
- The LCOE of the solar power system is $ 0.30 USD per kW. This is a bit high, but expected for rural areas in Africa.
- A thorough assessment of the electrical system is advised, with special attention to the grounding system and electrical safety.
- Correct use and maintenance of the solar power system is important to ensure continuous operation. Please see Appendix I (Operations) for recommended use and maintenance information.
- A checklist for periodical maintenance of the solar power system and the electrical system should be developed. This should be done after the installation is finished.
- If more funds become available, the most cost effective upgrade of the solar power system is to add more solar panels and charge controllers. Increasing the number of solar panels and charge controllers by 50 % has an estimated cost of $ 18 000 USD. This provides 40 kWh of extra available energy per day.
- If more solar panels are added, the battery capacity should be expanded to increase the autonomy of the solar power system.
- To deliver the total power demand at the hospital, the solar power system should have 360 solar panels. This would require an extensive upgrade of the solar power system, with an estimated cost of $ 259 000 USD.
- With an extensive upgrade, an AC-coupled system should be considered.
- Replacing equipment with more energy efficient products can be more cost effective than upgrading the solar power system.
- Before an extensive upgrade of the solar power system, the electrical system at the hospital should be upgraded focusing on electrical safety.

The assessment shows that the installed solar power system is satisfactory, given the invested funds, but the system should have been larger to cover all power needs. However, with correct use and maintenance, the system should provide a considerable amount of clean energy, giving the hospital a more reliable power source.

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List of Appendixes

Appendix A1

Teatre 1

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N	Watt/Døgn	Pr. Day	Pr. Night	Comment
Suction	1	100	100	1	6	0.10	10.00	8.00	2.00	80/20 D/N
Surgical lamps	1	550	550	60	6	6.00	3300.00	2640.00	660.00	80/20 D/N
Anesthesia equipment including ventilator	1	300	300	90	4	6.00	1800.00	1440.00	360.00	80/20 D/N
Fans	2	100	200	60	8	8.00	1600.00	1280.00	320.00	80/20 D/N
Lamps	1	300	300	60	8	8.00	2400.00	1920.00	480.00	80/20 D/N
Extra sockets	1	400	400	10	8	1.33	533.33	426.67	106.67	80/20 D/N
Air Condition	1	1500	1500	60	6	6.00	9000.00	7200.00	1800.00	80/20 D/N
Autoklave	1	2800	2800	120	1	2.00	5600.00	4480.00	1120.00	1 hour in the morning and one at end of day
Diathermia	1	600	600	1	20	0.33	200.00	160.00	40.00	80/20 D/N

Teatre 2

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				Comment
Suction	1	100	100	1	1.5	0.03	2.50	2.00	0.50	80/20 D/N
Surgical lamps	1	550	550	60	1.5	1.50	825.00	660.00	165.00	80/20 D/N
Anesthesia equipment including ventilator	1	300	300	90	1	1.50	450.00	360.00	90.00	80/20 D/N
Fans	2	100	200	60	2	2.00	400.00	320.00	80.00	80/20 D/N
Lamps	1	300	300	60	2	2.00	600.00	480.00	120.00	80/20 D/N
Extra sockets	1	400	400	10	2	0.33	133.33	106.67	26.67	80/20 D/N
Air Condition	1	1500	1500	60	1.5	1.50	2250.00	1800.00	450.00	80/20 D/N
Diathermia	1	600	600	1	5	0.08	50.00	40.00	10.00	80/20 D/N

Recovery Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Suction	1	100	100	1	4	0.07	6.67	5.33	1.33	80/20 D/N
Lamps	1	32	32	60	24	24.00	768.00	614.40	153.60	24 hours use
Fans	2	100	200	1440	1	24.00	4800.00	3840.00	960.00	80/20 D/N
ECG	1	100	100	1	5	0.08	8.33	6.67	1.67	80/20 D/N
Respirator	1	200	200	60	24	24.00	4800.00	3840.00	960.00	24 hours use
Extra Sockets	1	200	200	10	5	0.83	166.67	133.33	33.33	80/20 D/N

Meternity Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Suction	1	100	100	1	5	0.08	8.33	6.67	1.67	80/20 D/N
Lamps	1	560	560	60	5	5.00	2800.00	2240.00	560.00	Evening
Fans	2	100	200	60	24	24.00	4800.00	3840.00	960.00	24 hours use
Extra Sockets	1	300	300	5	4	0.33	100.00	80.00	20.00	80/20 D/N
Ultrasound	1	2000	2000	3	20	1.00	2000.00	1600.00	400.00	80/20 D/N
Surgical lamp	1	250	250	10	3	0.50	125.00	100.00	25.00	80/20 D/N
CTG Cardio Toco Graphy – for surveillance of fetus	1	200	200	30	2	1.00	200.00	160.00	40.00	80/20 D/N

General Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Lamps	1	160	160	60	5	5.00	800.00	640.00	160.00	Evening
Fans	6	100	600	1440	1	24.00	14400.00	11520.00	2880.00	24 hours use
Extra Sockets	1	300	300	10	6	1.00	300.00	240.00	60.00	80/20 D/N
Suction	1	100	100	1	5	0.08	8.33	6.67	1.67	80/20 D/N

Laboratory

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Refrigerator	1	150	150	1440	1	24.00	3600.00	2880.00	720.00	24 hours use
Lamps	1	24	24	60	2	2.00	48.00	38.40	9.60	80/20 D/N
Centrifuge	1	130	130	5	6	0.50	65.00	52.00	13.00	80/20 D/N
Extra Socket	1	100	100	10	5	0.83	83.33	66.67	16.67	80/20 D/N
App. For lab analyzis	1	200	200	4	10	0.67	133.33	106.67	26.67	80/20 D/N

Out-patient Clinic

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Refrigiator	1	150	150	1440	1	24.00	3600.00	2880.00	720.00	24 hours use
Lamps	1	24	24	60	4	4.00	96.00	76.80	19.20	80/20 D/N
PC	1	100	100	60	8	8.00	800.00	640.00	160.00	80/20 D/N
Extra Sockets	1	100	100	10	6	1.00	100.00	80.00	20.00	80/20 D/N

Kitchen

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Refrigiator	1	150	150	1440	1	24.00	3600.00	2880.00	720.00	24 hours use
Lamps	1	16	16	60	4	4.00	64.00	51.20	12.80	Evening
Fan	1	100	100	60	8	8.00	800.00	640.00	160.00	80/20 D/N
Micro wave	1	1000	1000	3	10	0.50	500.00	400.00	100.00	80/20 D/N
Extra sockets	1	200	200	10	5	0.83	166.67	133.33	33.33	80/20 D/N

Wound dressing room, Store and Farmacy

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
Refrigiator	1	100	100	1440	1	24.00	2400.00	1920.00	480.00	24 hours use
Lamps	1	32	32	60	4	4.00	128.00	102.40	25.60	Evening
Air Condition	1	500	500	1440	1	24.00	12000.00	9600.00	2400.00	24 hours use

Doctor's, CHO's and Matron's offices

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N				
PC	3	100	300	60	8	8.00	2400.00	1920.00	480.00	80/20 D/N
Lamps	1	32	32	60	4	4.00	128.00	102.40	25.60	80/20 D/N
Extra Sockets	1	50	50	20	6	2.00	100.00	80.00	20.00	80/20 D/N

Equipment	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Teatre 1																								
Suction	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Surgical lamps	41	41	41	41	41	41	41	41	330	330	330	330	330	330	330	330	41	41	41	41	41	41	41	41
Anesthesia equipment including ventilator	23	23	23	23	23	23	23	23	180	180	180	180	180	180	180	180	23	23	23	23	23	23	23	23
Fans	20	20	20	20	20	20	20	20	160	160	160	160	160	160	160	160	20	20	20	20	20	20	20	20
Lamps	30	30	30	30	30	30	30	30	240	240	240	240	240	240	240	240	30	30	30	30	30	30	30	30
Extra sockets	7	7	7	7	7	7	7	7	53	53	53	53	53	53	53	53	7	7	7	7	7	7	7	7
Air Condition	113	113	113	113	113	113	113	113	900	900	900	900	900	900	900	900	113	113	113	113	113	113	113	113
Autoklave																	2800	2800						
Diathermia	3	3	3	3	3	3	3	3	20	20	20	20	20	20	20	20	3	3	3	3	3	3	3	3
	236	236	236	236	236	236	236	236	1884	1884	1884	1884	1884	1884	1884	1884	3036	3036	236	236	236	236	236	236
Teatre 2																								
Suction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surgical lamps	10	10	10	10	10	10	10	10	83	83	83	83	83	83	83	83	10	10	10	10	10	10	10	10
Anesthesia equipment including ventilator	6	6	6	6	6	6	6	6	45	45	45	45	45	45	45	45	6	6	6	6	6	6	6	6
Fans	5	5	5	5	5	5	5	5	40	40	40	40	40	40	40	40	5	5	5	5	5	5	5	5
Lamps	8	8	8	8	8	8	8	8	60	60	60	60	60	60	60	60	8	8	8	8	8	8	8	8
Extra sockets	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
Air Condition	28	28	28	28	28	28	28	28	225	225	225	225	225	225	225	225	28	28	28	28	28	28	28	28
Diathermia	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	1	1	1	1	1	1	1	1
	59	59	59	59	59	59	59	59	471	471	471	471	471	471	471	471	59	59	59	59	59	59	59	59
Recovery Ward																								
Suction	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Lamps	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Fans	60	60	60	60	60	60	60	60	480	480	480	480	480	480	480	480	60	60	60	60	60	60	60	60
ECG	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Respirator	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Extra Sockets	2	2	2	2	2	2	2	2	17	17	17	17	17	17	17	17	2	2	2	2	2	2	2	2
	294	294	294	294	294	294	294	294	730	730	730	730	730	730	730	730	294	294	294	294	294	294	294	294
Meternity Ward																								
Suction	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Lamps																			560	560	560	560	560	
Fans	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Extra Sockets	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
Ultrasound	25	25	25	25	25	25	25	25	200	200	200	200	200	200	200	200	25	25	25	25	25	25	25	25
Surgical lamp	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
CTG	3	3	3	3	3	3	3	3	20	20	20	20	20	20	20	20	3	3	3	3	3	3	3	3
	230	230	230	230	230	230	230	230	443	443	443	443	443	443	443	443	230	230	790	790	790	790	790	230
General Ward																								
Lamps																			160	160	160	160	160	
Fans	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Extra Sockets	4	4	4	4	4	4	4	4	30	30	30	30	30	30	30	30	4	4	4	4	4	4	4	4
Suction	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
	604	604	604	604	604	604	604	604	631	631	631	631	631	631	631	631	604	604	764	764	764	764	764	604
Laboratory																								
Refrigerator	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Lamps	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	1	1	1	1	1	1	1	1
Centrifuge	1	1	1	1	1	1	1	1	7	7	7	7	7	7	7	7	1	1	1	1	1	1	1	1
Extra Socket	1	1	1	1	1	1	1	1	8	8	8	8	8	8	8	8	1	1	1	1	1	1	1	1
App. For lab analyzis	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
	154	154	154	154	154	154	154	154	183	183	183	183	183	183	183	183	154	154	154	154	154	154	154	154
Out-patient Clinic																								
Refrigiator	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Lamps	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
PC	10	10	10	10	10	10	10	10	80	80	80	80	80	80	80	80	10	10	10	10	10	10	10	10
Extra Sockets	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
	162	162	162	162	162	162	162	162	250	250	250	250	250	250	250	250	162	162	162	162	162	162	162	162
Kitchen																								
Refrigiator	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Lamps																			16	16	16	16		
Fan	10	10	10	10	10	10	10	10	80	80	80	80	80	80	80	80	10	10	10	10	10	10	10	10
Micro wave	6	6	6	6	6	6	6	6	50	50	50	50	50	50	50	50	6	6	6	6	6	6	6	6
Extra sockets	2	2	2	2	2	2	2	2	17	17	17	17	17	17	17	17	2	2	2	2	2	2	2	2
	168	168	168	168	168	168	168	168	297	297	297	297	297	297	297	297	168	168	184	184	184	184	168	168
Wound dressing room, Store and Farmacy																								
Refrigiator	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Lamps																			32	32	32	32		
Air Condition	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	632	632	632	632	600	600
Doctor's, CHO's and Matron's offices																								
PC	30	30	30	30	30	30	30	30	240	240	240	240	240	240	240	240	30	30	30	30	30	30	30	30
Lamps	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
Extra Sockets	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
	33	33	33	33	33	33	33	33	263	263	263	263	263	263	263	263	33	33	33	33	33	33	33	33

Appendix A1

Ambulance house

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	10	10	60	12	12.00	120.00	96.00	24.00 80/20 D/N	2	2	2	2	2	2	2	2	12	12	12	12	12	12	12	12	2	2	2	2	2	2	2	2
Extra Sockets	1	200	200	60	2	2.00	400.00	320.00	80.00 80/20 D/N	5	5	5	5	5	5	5	5	40	40	40	40	40	40	40	40	5	5	5	5	5	5	5	5
										7	7	7	7	7	7	7	7	52	52	52	52	52	52	52	52	7	7	7	7	7	7	7	7

Acute ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	16	16	60	12	12.00	192.00	153.60	38.40 Night time	16	16	16	16	16	16													16	16	16	16	16	16
Extra Sockets	1	400	400	60	3	3.00	1200.00	960.00	240.00 80/20 D/N	15	15	15	15	15	15	15	15	120	120	120	120	120	120	120	120	15	15	15	15	15	15	15	15
										31	31	31	31	31	31	15	15	120	120	120	120	120	120	120	120	15	15	31	31	31	31	31	31

Dentistry (GENERATOR, Not supplied by Solar Panel/Batteries)

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N
Lamps	1	16	16	60	8	8.00
Unit	1	2500	2500	60	3	

Waiting area/Gate

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	16	16	60	12	12.00	192.00	153.60	38.40 Night time	16	16	16	16	16	16													16	16	16	16	16	16
										16	16	16	16	16	16	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16	16	16	16

Church

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	50	50	60	4	4.00	200.00	160.00	40.00 Evening																				50	50	50	50	
Extrac Sockets	1	100	100	60	2	2.00	200.00	160.00	40.00 Evening																				100	100			
										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	150	50	50	0

Walking path

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	48	48	60	12	12.00	576.00	460.80	115.20 Night time	48	48	48	48	48	48													48	48	48	48	48	48
										48	48	48	48	48	48	0	0	0	0	0	0	0	0	0	0	0	0	48	48	48	48	48	48

Haugesund house

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	40	40	60	5	5.00	200.00	160.00	40.00 Evening																			40	40	40	40	40	
Fans	5	100	500	60	8	8.00	4000.00	3200.00	800.00 Evening																	500	500	500	500	500	500	500	500
Refigerator	1	150	150	60	24	24.00	3600.00	2880.00	720.00 24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
TV/Video	1	150	150	60	2	2.00	300.00	240.00	60.00 Evening																				150	150			
Stereo	1	100	100	60	2	2.00	200.00	160.00	40.00 Evening																				100	100			
PC	3	100	300	60	2	2.00	600.00	480.00	120.00 Evening																				300	300			
										150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	650	650	690	1240	1240	690	690	650

Doctors house

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	40	40	60	5	5.00	200.00	160.00	40.00 Evening																			40	40	40	40	40	
Fans	6	100	600	60	8	8.00	4800.00	3840.00	960.00 Evening	600																	600	600	600	600	600	600	600
Refigerator	1	150	150	60	24	24.00	3600.00	2880.00	720.00 24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
TV/Video	1	150	150	60	2	2.00	300.00	240.00	60.00 Evening																				150	150			
Stereo	1	100	100	60	2	2.00	200.00	160.00	40.00 Evening																				100	100			
PC	2	100	200	60	2	2.00	400.00	320.00	80.00 Evening																				200	200			
										750	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	750	790	1240	1240	790	790	750

Staff house

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No of hours	Total hours pr D/N																											
Lamps	1	40	40	60	5	5.00	200.00	160.00	40.00 Evening																			40	40	40	40	40	
Fans	4	100	400	60	8	8.00	3200.00	2560.00	640.00 Evening	400																	400	400	400	400	400	400	400
Refigerator	1	150	150	60	24	24.00	3600.00	2880.00	720.00 24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
							124537.83			550	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	550	590	590	590	590	590	550

Battery Enclosure

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. hour	No og hours	Total hours pr D/N																											
Air Condition	1	750	750	60	24	24	18000			250	250	250	250	250	250	250	250	500	500	750	750	750	750	750	750	750	750	750	500	500	500	500	250

4342	**3342**	**3342**	**3342**	**3342**	**3342**	**3262**	**3262**	**6874**	**6874**	**7124**	**7124**	**7124**	**7124**	**7124**	**7124**	**7062**	**8062**	**6230**	**7130**	**7130**	**6030**	**5982**	**4842**
																						Sum:	**136538**
4668	3593	3593	3593	3593	3593	3507	3507	7389	7389	7658	7658	7658	7658	7658	7658	7592	8667	6697	7665	7665	6482	6431	5205

Inverter

Power consumption multiplied by 1,075 (+ 7,5% power consumption)

Sum	146778

Appendix A2

Teatre 1

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N	W/24 hours	Pr. Day	Pr. Night	Comment	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	
Suction	1	100	100	1	6	0.10	10.00	8.00	2.00	80/20 D/N	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	
Surgical lamps	1	550	550	60	6	6.00	3300.00	2640.00	660.00	80/20 D/N	41	41	41	41	41	41	41	41	330	330	330	330	330	330	330	330	41	41	41	41	41	41	41	41	
Anesthesia equipment including ventilator	1	300	300	90	4	6.00	1800.00	1440.00	360.00	80/20 D/N	23	23	23	23	23	23	23	23	180	180	180	180	180	180	180	180	23	23	23	23	23	23	23	23	
Fans	2	100	200	60	8	8.00	1600.00	1280.00	320.00	80/20 D/N	20	20	20	20	20	20	20	20	160	160	160	160	160	160	160	160	20	20	20	20	20	20	20	20	
Lamps	1	300	300	60	8	8.00	2400.00	1920.00	480.00	80/20 D/N	30	30	30	30	30	30	30	30	240	240	240	240	240	240	240	240	30	30	30	30	30	30	30	30	
Extra sockets	1	400	400	10	8	1.33	533.33	426.67	106.67	80/20 D/N	7	7	7	7	7	7	7	7	53	53	53	53	53	53	53	53	7	7	7	7	7	7	7	7	
Air Condition	2	1880	3760	60	6	6.00	22560.00	18048.00	4512.00	80/20 D/N	282	282	282	282	282	282	282	282	2256	2256	2256	2256	2256	2256	2256	2256	282	282	282	282	282	282	282	282	22560
Autoklave	1	2800	2800	120	1	2.00	5600.00	5600.00		Used at the end of the day																	2800	2800							
Diathermia	1	600	600	1	20	0.33	200.00	160.00	40.00	80/20 D/N	3	3	3	3	3	3	3	3	20	20	20	20	20	20	20	20	3	3	3	3	3	3	3	3	
Hjertestarter											405	405	405	405	405	405	405	405	3240	3240	3240	3240	3240	3240	3240	3240	3205	3205	405	405	405	405	405	405	

Teatre 2

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N				Comment	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Suction	1	100	100	1	1.5	0.03	2.50	2.00	0.50	80/20 D/N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surgical lamps	1	550	550	60	1.5	1.50	825.00	660.00	165.00	80/20 D/N	10	10	10	10	10	10	10	10	83	83	83	83	83	83	83	83	10	10	10	10	10	10	10	10
Anesthesia equipment including ventilator	1	300	300	90	1	1.50	450.00	360.00	90.00	80/20 D/N	6	6	6	6	6	6	6	6	45	45	45	45	45	45	45	45	6	6	6	6	6	6	6	6
Fans	2	100	200	60	2	2.00	400.00	320.00	80.00	80/20 D/N	5	5	5	5	5	5	5	5	40	40	40	40	40	40	40	40	5	5	5	5	5	5	5	5
Lamps	1	300	300	60	2	2.00	600.00	480.00	120.00	80/20 D/N	8	8	8	8	8	8	8	8	60	60	60	60	60	60	60	60	8	8	8	8	8	8	8	8
Extra sockets	1	400	400	10	2	0.33	133.33	106.67	26.67	80/20 D/N	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
Air Condition	1	1880	1880	60	3	3.00	5640.00	4512.00	1128.00	80/20 D/N	71	71	71	71	71	71	71	71	564	564	564	564	564	564	564	564	71	71	71	71	71	71	71	71
Diathermia	1	600	600	1	5	0.08	50.00	40.00	10.00	80/20 D/N	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	1	1	1	1	1	1	1	1
											101	101	101	101	101	101	101	101	810	810	810	810	810	810	810	810	101	101	101	101	101	101	101	101

Recovery Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Suction	1	100	100	1	4	0.07	6.67	5.33	1.33	80/20 D/N	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Lamps	1	32	32	60	24	24.00	768.00			24 hours use	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Fans	2	100	200	1440	1	24.00	4800.00	3840.00	960.00	80/20 D/N	60	60	60	60	60	60	60	60	480	480	480	480	480	480	480	480	60	60	60	60	60	60	60	60
Aircondition	1	1250	1250	60	8	8.00	10000.00	8000.00	2000.00	80/20 D/N	125	125	125	125	125	125	125	125	1000	1000	1000	1000	1000	1000	1000	1000	125	125	125	125	125	125	125	125
Respirator	1	200	200	60	24	24.00	4800.00			24 hours use	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Extra Sockets	1	200	200	10	5	0.83	166.67	133.33	33.33	80/20 D/N	2	2	2	2	2	2	2	2	17	17	17	17	17	17	17	17	2	2	2	2	2	2	2	2
											419	419	419	419	419	419	419	419	1729	1729	1729	1729	1729	1729	1729	1729	419	419	419	419	419	419	419	419

Meternity Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Suction	1	100	100	1	5	0.08	8.33	6.67	1.67	80/20 D/N	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Lamps	1	560	560	60	5	5.00	2800.00			Evening																			560	560	560	560	560	
Fans	2	100	200	60	24	24.00	4800.00			24 hours use	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Extra Sockets	1	300	300	5	4	0.33	100.00	80.00	20.00	80/20 D/N	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
Ultrasound	1	2000	2000	3	20	1.00	2000.00	1600.00	400.00	80/20 D/N	25	25	25	25	25	25	25	25	200	200	200	200	200	200	200	200	25	25	25	25	25	25	25	25
Surgical lamp	1	250	250	10	3	0.50	125.00	100.00	25.00	80/20 D/N	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
CTG Cardio Toco Graphy – for surveillance of fetus	1	200	200	30	2	1.00	200.00	160.00	40.00	80/20 D/N	3	3	3	3	3	3	3	3	20	20	20	20	20	20	20	20	3	3	3	3	3	3	3	3
											230	230	230	230	230	230	230	230	443	443	443	443	443	443	443	443	230	230	790	790	790	790	790	230

General Ward

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Lamps	1	160	160	60	5	5.00	800.00			Evening																			160	160	160	160	160	
Fans	6	100	600	1440	1	24.00	14400.00			24 hours use	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Extra Sockets	1	300	300	10	6	1.00	300.00	240.00	60.00	80/20 D/N	4	4	4	4	4	4	4	4	30	30	30	30	30	30	30	30	4	4	4	4	4	4	4	4
Suction	1	100	100	1	5	0.08	8.33	6.67	1.67	80/20 D/N	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
											604	604	604	604	604	604	604	604	631	631	631	631	631	631	631	631	604	604	764	764	764	764	764	604

Laboratory

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Refrigerator	1	150	150	1440	1	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Lamps	1	24	24	60	2	2.00	48.00	38.40	9.60	80/20 D/N	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	1	1	1	1	1	1	1	1
Centrifuge	1	130	130	5	6	0.50	65.00	52.00	13.00	80/20 D/N	1	1	1	1	1	1	1	1	7	7	7	7	7	7	7	7	1	1	1	1	1	1	1	1
Extra Socket	1	100	100	10	5	0.83	83.33	66.67	16.67	80/20 D/N	1	1	1	1	1	1	1	1	8	8	8	8	8	8	8	8	1	1	1	1	1	1	1	1
App. For lab analyzis	1	200	200	4	10	0.67	133.33	106.67	26.67	80/20 D/N	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
											154	154	154	154	154	154	154	154	183	183	183	183	183	183	183	183	154	154	154	154	154	154	154	154

Out-patient Clinic

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Refrigiator	1	150	150	1440	1	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
AirCondition	4	5640	22560	60	8	8.00	180480.00	144384.00	36096.00	80/20 D/N	2256	2256	2256	2256	2256	2256	2256	2256	18048	18048	18048	18048	18048	18048	18048	18048	2256	2256	2256	2256	2256	2256	2256	2256
PC	1	100	100	60	8	8.00	800.00	640.00	160.00	80/20 D/N	10	10	10	10	10	10	10	10	80	80	80	80	80	80	80	80	10	10	10	10	10	10	10	10
Extra Sockets	1	100	100	10	6	1.00	100.00	80.00	20.00	80/20 D/N	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1
											2417	2417	2417	2417	2417	2417	2417	2417	18288	18288	18288	18288	18288	18288	18288	18288	2417	2417	2417	2417	2417	2417	2417	2417

Kitchen

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Refrigiator	1	150	150	1440	1	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Lamps	1	16	16	60	4	4.00	64.00			Evening																			16	16	16	16		
Fan	1	100	100	60	8	8.00	800.00	640.00	160.00	80/20 D/N	10	10	10	10	10	10	10	10	80	80	80	80	80	80	80	80	10	10	10	10	10	10	10	10
Micro wave	1	1000	1000	3	10	0.50	500.00	400.00	100.00	80/20 D/N	6	6	6	6	6	6	6	6	50	50	50	50	50	50	50	50	6	6	6	6	6	6	6	6
Extra sockets	1	200	200	10	5	0.83	166.67	133.33	33.33	80/20 D/N	2	2	2	2	2	2	2	2	17	17	17	17	17	17	17	17	2	2	2	2	2	2	2	2
											168	168	168	168	168	168	168	168	297	297	297	297	297	297	297	297	168	168	184	184	184	184	168	168

Wound dressing room, Store and Farmacy

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Refrigiator	1	100	100	1440	1	24.00	2400.00			24 hours use	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Lamps	1	32	32	60	4	4.00	128.00			Evening																			32	32	32	32		
Air Condition	1	500	500	1440	1	24.00	12000.00			24 hours use	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
											600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	632	632	632	632	600	600

Doctor's, CHO's and Matron's offices

Equipment	No of units	Consumption in Watt/unit	Total Consumption	Minutes used pr. time	No of times	Total hours pr D/N					00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
PC	3	100	300	60	8	8.00	2400.00	1920.00	480.00	80/20 D/N	30	30	30	30	30	30	30	30	240	240	240	240	240	240	240	240	30	30	30	30	30	30	30	30
Lamps	1	32	32	60	4	4.00	128.00	102.40	25.60	80/20 D/N	2	2	2	2	2	2	2	2	13	13	13	13	13	13	13	13	2	2	2	2	2	2	2	2
Aircondition	1	1250	1250	60	6	6.00	7500.00	6000.00	1500.00	80/20 D/N									1250	1250	1250	1250	1250	1250	1250	1250								

Appendix A2

											32	32	32	32	32	32	32	32	1503	1503	1503	1503	1503	1503	1503	1503	32	32	32	32	32	32	32	32
Ambulance house																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	10	10	60	12	12.00	120.00	96.00	24.00	80/20 D/N	2	2	2	2	2	2	2	2	12	12	12	12	12	12	12	12	2	2	2	2	2	2	2	2
Extra Sockets	1	200	200	60	2	2.00	400.00	320.00	80.00	80/20 D/N	5	5	5	5	5	5	5	5	40	40	40	40	40	40	40	40	5	5	5	5	5	5	5	5
											7	7	7	7	7	7	7	7	52	52	52	52	52	52	52	52	7	7	7	7	7	7	7	7
Acute ward																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	16	16	60	12	12.00	192.00			Night time	16	16	16	16	16	16													16	16	16	16	16	16
Extra Sockets	1	400	400	60	3	3.00	1200.00	960.00	240.00	80/20 D/N	15	15	15	15	15	15	15	15	120	120	120	120	120	120	120	120	15	15	15	15	15	15	15	15
											31	31	31	31	31	31	15	15	120	120	120	120	120	120	120	120	15	15	31	31	31	31	31	31
Dentistry (GENERATOR, Not supplied by Solar Panel/Batteries)																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	16	16	60	8	8.00																												
Unit	1	2500	2500	60	3																													
Waiting area/Gate																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	16	16	60	12	12.00	192.00			Night time	16	16	16	16	16	16													16	16	16	16	16	16
											16	16	16	16	16	16	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16	16	16	16
Church																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	50	50	60	4	4.00	200.00			Evening																				50	50	50	50	
Extrac Sockets	1	100	100	60	2	2.00	200.00			Evening																				100	100			
											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	150	50	50	0
Walking path																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	48	48	60	12	12.00	576.00			Night time	48	48	48	48	48	48													48	48	48	48	48	48
											48	48	48	48	48	48	0	0	0	0	0	0	0	0	0	0	0	0	48	48	48	48	48	48
Haugesund house																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	40	40	60	5	5.00	200.00			Evening																			40	40	40	40	40	
Fans	5	100	500	60	8	8.00	4000.00			Evening																	500	500	500	500	500	500	500	500
Refigerator	1	150	150	60	24	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
TV/Video	1	150	150	60	2	2.00	300.00			Evening																				150	150			
Stereo	1	100	100	60	2	2.00	200.00			Evening																				100	100			
PC	3	100	300	60	2	2.00	600.00			Evening																				300	300			
											150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	650	650	690	1240	1240	690	690	650
Doctors house																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	40	40	60	5	5.00	200.00			Evening																			40	40	40	40	40	
Fans	6	100	600	60	8	8.00	4800.00			Evening	600																	600	600	600	600	600	600	600
Refigerator	1	150	150	60	24	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
TV/Video	1	150	150	60	2	2.00	300.00			Evening																				150	150			
Aircondition	1	1250	1250	60	5	5.00	6250.00			Evening																	1225	1225	1225	1225	1225			
PC	2	100	200	60	2	2.00	400.00			Evening																				200	200			
											750	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	1375	1975	2015	2365	2365	790	790	750
Staff house																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. time**	**No of times**	**Total hours pr D/N**																												
Lamps	1	40	40	60	5	5.00	200.00			Evening																			40	40	40	40	40	
Fans	4	100	400	60	8	8.00	3200.00			Evening	400																	400	400	400	400	400	400	400
Refigerator	1	150	150	60	24	24.00	3600.00			24 hours use	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
							345313.50				550	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	550	590	590	590	590	590	550
Battery Enclosure																																		
Equipment	**No of units**	**Consumption in Watt/unit**	**Total Consumption**	**Minutes used pr. hour**	**No og hours**	**Total hours pr D/N**																												
Air Condition	1	750	750	60	24	24	18000				250	250	250	250	250	250	250	250	500	500	750	750	750	750	750	750	750	750	750	500	500	500	500	250
											6933	**5933**	**5933**	**5933**	**5933**	**5933**	**5853**	**5853**	**28846**	**28846**	**29096**	**29096**	**29096**	**29096**	**29096**	**29096**	**10878**	**11878**	**10046**	**10846**	**10846**	**8621**	**8573**	**7433**
Inverter																																	**Sum**	**359689**
Power consumption multiplied by 1,075 (+ 7,5% power consumption)											7452	6377	6377	6377	6377	6377	6291	6291	31010	31010	31279	31279	31279	31279	31279	31279	11693	12768	10799	11659	11659	9267	9215	7990
																																	Sum	386665

Appendix B

Config #	Solar Panels	Batteries	Charge Controllers	Inverters	kVA Continuous	kVA Peak 30min	Estimated Cost USD	User Need kWh/day	Available Energy MWh/year	Cost per available energy	Specific Production	Used Energy MWh/year	Excess (unused) MWh/year	Performance Ratio PR	Solar Fraction SF	Battery Capacity Ah	Time Fraction	Missing Energy MWh/year
1.1	80	24x3220Ah	4	3	20,4	25,5	104289	137	29,3	3562	1464	28,7	0	76	**54**	3220	56	24,9
1.2	120	24x2140Ah	6	3	20,4	25,5	104916		43,9	2389	1464	42,1	0,16	74	**79**	2140	29	11,5
1.3	60	48x2140Ah	3	3	20,4	25,5	112274		22,0	5113	1464	20,8	0	73	**39**	4280	62	32,8
	270	96x3220Ah	9	6	40,8	51,0	353000	137										
2.1	80	48x3220Ah	4	3	20,4	25,5	51408	137	29,3		1464	28,6	0	76	**53**	6440	48	25,0
2.2	120	24x3220Ah	6	3	20,4	25,5	17871		43,9	1222	1464	43,0	0	76	**80**	3220	13	10,6
2.3	120	48x3220Ah	6	3	20,4	25,5	69279		43,9	4735	1464	43,2	0	76	**81**	6440	21	10,4
3.1	160	48x3220Ah	8	6	40,8	51,0	104289	360	58,6	3561	1463	56,7	0	75	**40**	6440	77	83,4
3.2	160	96x3220Ah	8	6	40,8	51,0	207105		58,5	7085	1463	57,2	0	76	**40**	12880	57	84,0
3.3	240	48x3220Ah	12	6	40,8	51,0	140031		87,8	2392	1464	86,2	0	76	**61**	6440	56	54,9
3.4	240	96x3220Ah	12	6	40,8	51,0	242847		87,8	4148	1464	86,4	0	76	**61**	12880	35	54,7
3.5	240	72x3220Ah	12	9	61,2	76,5	208578		87,8	3563	1464	86,5	0	76	**61**	9660	45	54,7
3.6	240	144x3220Ah	12	9	61,2	76,5	362802		87,8	6198	1464	86,4	0	76	**61**	19320	40	54,7
3.7	360	72x3220Ah	18	9	61,2	76,5	258840		132,0	2520	1466	125,5	0	74	**89**	9660	13	15,7
3.8	360	144x3220Ah	18	9	61,2	76,5	406362		131,9	3960	1465	126,8	2,5	75	**90**	19320	11	14,4

Appendix C1

Stand Alone System: Simulation parameters

Project : **Project_Rotifunk**

Geographical Site		**Rotifunk**	Country	**Sierra Leone**
Situation	Latitude	8.19° N	Longitude	-12.66° W
Time defined as	Legal Time	Time zone UT	Altitude	28 m
	Albedo	0.20		
Meteo data:	**Rotifunk**	Meteonorm 7.1 (1971-1980), Sat=100% - Synthetic		

Simulation variant : **Rotifunk_Project_EFO_80-Panels_24-Batteries_4-ChargeCont.**

Simulation date 30/03/17 10h09

Simulation parameters

Collector Plane Orientation	Tilt	12°	Azimuth	-10°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm

PV Array Characteristics

PV module Si-poly	Model	**HSC 60 Poly Can-Am**		
Custom parameters definition	Manufacturer	Hanwha Solar		
Number of PV modules	In series	10 modules	In parallel	8 strings
Total number of PV modules	Nb. modules	80	Unit Nom. Power	250 Wp
Array global power	Nominal (STC)	**20.00 kWp**	At operating cond.	17.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	272 V	I mpp	66 A
Total area	Module area	**131 m²**	Cell area	117 m²

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	70 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.2 % at STC
Module Quality Loss			Loss Fraction	1.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP

Incidence effect (IAM): User defined IAM profile

0°	40°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	0.990	0.970	0.900	0.830	0.700	0.460	0.000

System Parameter	System type	**Stand Alone System**		
Battery	Model	**S2-3220GEL**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	3220 Ah
	Nb. of units	24 in series		
	Temperature	Fixed (25°C)		
Controller	Model	Conext_MPPT_80_600 - 48V		
	Manufacturer	Schneider Electric	nb units	4
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	96.0/93.6 %		
Battery management control	Treshold commands as	Battery voltage		
	Charging	54.9 / 50.2 V	Corresp. SOC	0.90 / 0.61
	Discharging	45.5 / 48.9 V	Corresp. SOC	0.12 / 0.31
User's needs :	daily profile	Constant over the year		
	average	147 kWh/Day		

Appendix C1

Stand Alone System: Detailed User's needs

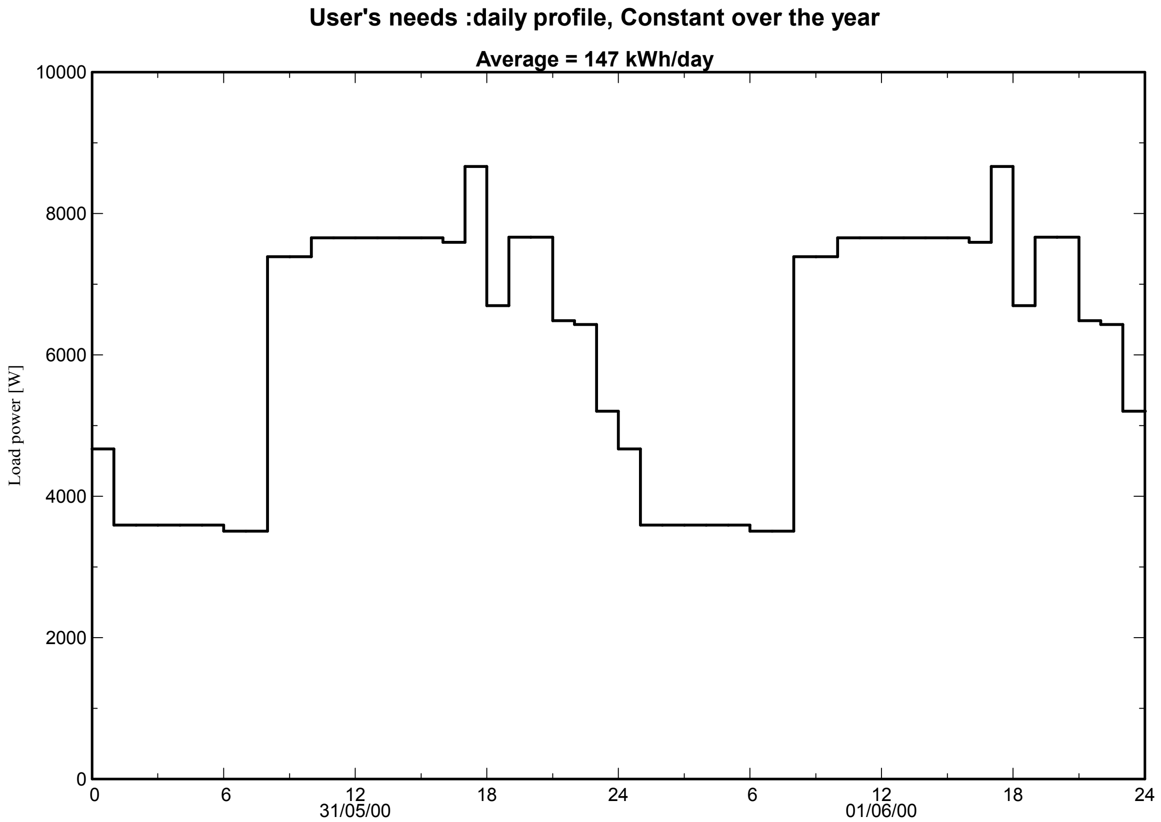
Project : **Project_Rotifunk**

Simulation variant : **Rotifunk_Project_EFO_80-Panels_24-Batteries_4-ChargeCont.**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	12°	azimuth	-10°
PV modules	Model	HSC 60 Poly Can-Am	Pnom	250 Wp
PV Array	Nb. of modules	80	Pnom total	**20.00 kWp**
Battery	Model	S2-3220GEL	Technology	sealed, Gel
battery Pack	Nb. of units	24	Voltage / Capacity	**48 V / 3220 Ah**
User's needs	daily profile	Constant over the year	global	53.6 MWh/year

daily profile, Constant over the year, average = 147 kWh/day

	0 h 12 h	1 h 13 h	2 h 14 h	3 h 15 h	4 h 16 h	5 h 17 h	6 h 18 h	7 h 19 h	8 h 20 h	9 h 21 h	10 h 22 h	11 h 23 h	
Hourly load	4.67 7.66	3.59 7.66	3.59 7.66	3.59 7.66	3.59 7.59	3.59 8.67	3.51 6.70	3.51 7.66	7.39 7.66	7.39 6.48	7.66 6.43	7.66 5.21	kW kW



Appendix C1

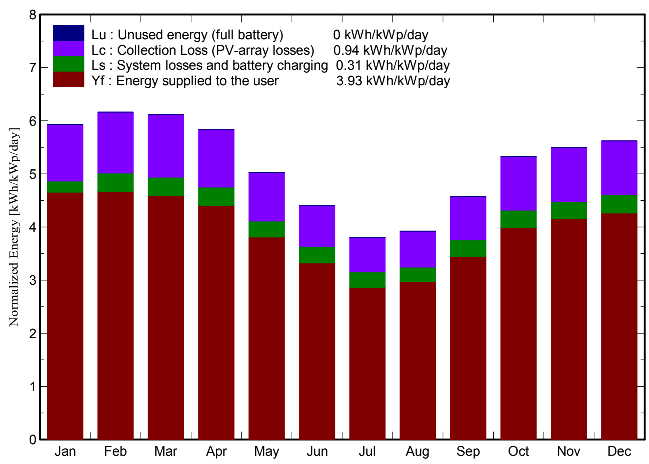
Stand Alone System: Main results

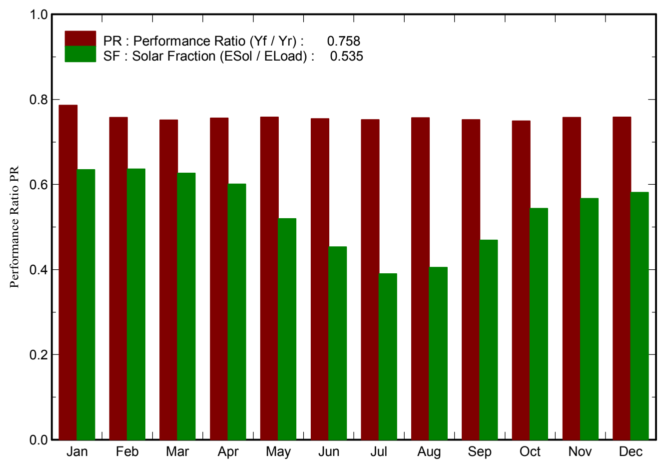
Project : **Project_Rotifunk**

Simulation variant : **Rotifunk_Project_EFO_80-Panels_24-Batteries_4-ChargeCont.**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	12°	azimuth	-10°
PV modules	Model	HSC 60 Poly Can-Am	Pnom	250 Wp
PV Array	Nb. of modules	80	Pnom total	**20.00 kWp**
Battery	Model	S2-3220GEL	Technology	sealed, Gel
battery Pack	Nb. of units	24	Voltage / Capacity	**48 V / 3220 Ah**
User's needs	daily profile	Constant over the year	global	53.6 MWh/year

Main simulation results				
System Production	**Available Energy**	**29.28 MWh/year**	Specific prod.	1464 kWh/kWp/year
	Used Energy	28.67 MWh/year	Excess (unused)	0.00 MWh/year
	Performance Ratio PR	75.82 %	Solar Fraction SF	53.51 %
Loss of Load	Time Fraction	56.2 %	Missing Energy	24.91 MWh/year





Rotifunk_Project_EFO_80-Panels_24-Batteries_4-ChargeCont.

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	168.0	180.1	2.866	0.000	1.660	2.890	4.550	0.635
February	163.2	169.2	2.668	0.000	1.493	2.617	4.110	0.637
March	186.2	185.5	2.906	0.000	1.698	2.852	4.550	0.627
April	179.0	170.9	2.703	0.000	1.756	2.648	4.403	0.601
May	165.1	151.5	2.417	0.000	2.187	2.363	4.550	0.519
June	141.2	128.3	2.060	0.000	2.407	1.996	4.403	0.453
July	125.2	114.1	1.837	0.000	2.774	1.776	4.550	0.390
August	125.9	117.9	1.894	0.000	2.708	1.843	4.550	0.405
September	137.7	133.8	2.127	0.000	2.336	2.068	4.403	0.470
October	158.6	161.0	2.541	0.000	2.076	2.474	4.550	0.544
November	152.1	161.1	2.548	0.000	1.906	2.497	4.403	0.567
December	157.7	170.7	2.712	0.000	1.905	2.645	4.550	0.581
Year	1859.9	1844.1	29.280	0.001	24.906	28.667	53.573	0.535

Legends:				
GlobHor	Horizontal global irradiation		E Miss	Missing energy
GlobEff	Effective Global, corr. for IAM and shadings		E User	Energy supplied to the user
E Avail	Available Solar Energy		E Load	Energy need of the user (Load)
EUnused	Unused energy (full battery) loss		SolFrac	Solar fraction (EUsed / ELoad)

Appendix C1

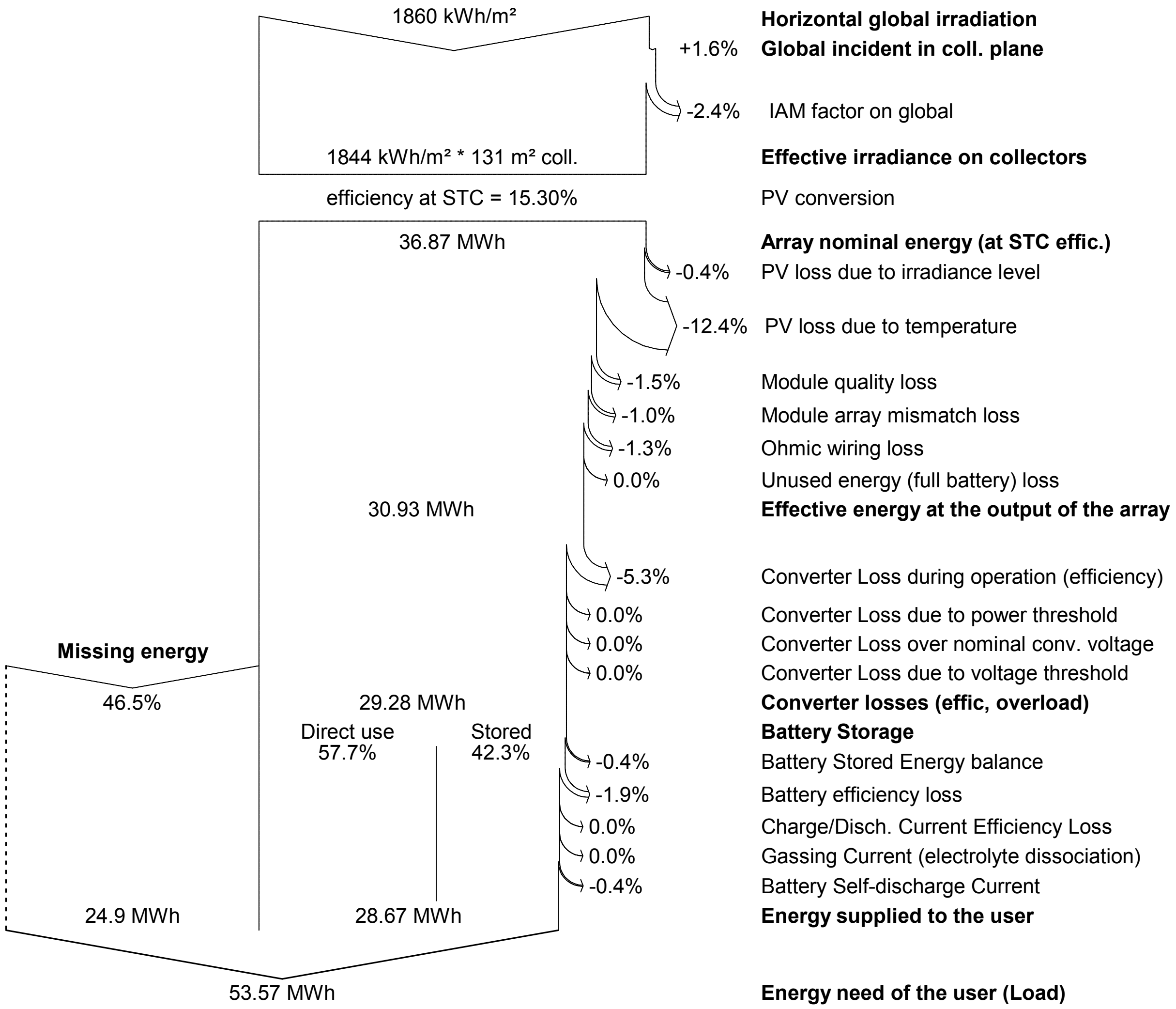
Stand Alone System: Loss diagram

Project : **Project_Rotifunk**

Simulation variant : **Rotifunk_Project_EFO_80-Panels_24-Batteries_4-ChargeCont.**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	12°	azimuth	-10°
PV modules	Model	HSC 60 Poly Can-Am	Pnom	250 Wp
PV Array	Nb. of modules	80	Pnom total	**20.00 kWp**
Battery	Model	S2-3220GEL	Technology	sealed, Gel
battery Pack	Nb. of units	24	Voltage / Capacity	**48 V / 3220 Ah**
User's needs	daily profile	Constant over the year	global	53.6 MWh/year

Loss diagram over the whole year



Appendix C2

Calculated Solar Fraction

The total PV array area with the 80 units of the 250 W Hanwha Solar Panel in EFO`s tender is 131 m^2. Based on the sized area and the irradiance data at the site location, the maximum calculated solar fraction in the months of highest and lowest irradiance will be:

	March	**July**
Irradiance	6 kWh/m^2pr.day	4 kWh/m^2pr.day

Please see Appendix D (Solar Irradiance Data at Rotifunk) for further data.

The daily energy demand is calculated to be 136.538 kWh per day at the hospital.

$$E_{max.}(kWh) = PV\ Array\ Area \times H \times \eta_{PV} \times T_{cell-eff.} \times \eta_{out} \quad (4)$$

E_{max} = Max. Energy (Wh)
H= Solar Irradiance (kWh/m^2)
$T_{cell\text{-}eff.}$ = Cell Temperature Efficiency Correction Factor
η_{out}= Charge Controller Efficiency × Battery Efficiency × Inverter Efficiency × Cable Loss

This is same equation as explained in Chapter 3.3 - Solar Power System Calculations

Table C.1 – Solar Power System in EFO`s Tender

Daily Energy Demand	136.538 kWh
PV Array Efficiency	15.3 %
Cell Temperature Correction Factor	0.886
Charge Controller Efficiency (Nom. 48 V)	94 %
Inverters Efficiency CEC	92.5 %
Cable Loss	3 %
Battery Efficiency	80 %

July - The month of lowest irradiance

$$E_{max.} = 4\frac{kWh}{m^2} \times 131 m^2 \times 0.153 \times 0.886 \times 0.67 = 48\ kWh \quad (4)$$

Max. solar fraction for July:

$$Solar\ Fraction\ (\%) = \frac{48\ kWh \times 100}{136.5\ kWh} = 35\ \% \quad (14)$$

This gives the missing energy in percentage:

$$Missing\ Energy\ (\%) = (100 - 35)\ \% = 65\ \%$$

March- The month of highest irradiance

$$E_{max.} = 6\frac{kWh}{m^2} \times 131 m^2 \times 0.153 \times 0.886 \times 0.67 = 71\ kWh \quad (4)$$

Max. solar fraction for March:

$$Solar\ Fraction\ (\%) = \frac{71\ kWh \times 100}{136.5\ kWh} = 52\ \% \quad (14)$$

This gives the missing energy in percentage:

$$Missing\ Energy\ (\%) = (100 - 52)\ \% = 48\ \%$$

Appendix C3

Generated Energy over 20 Years

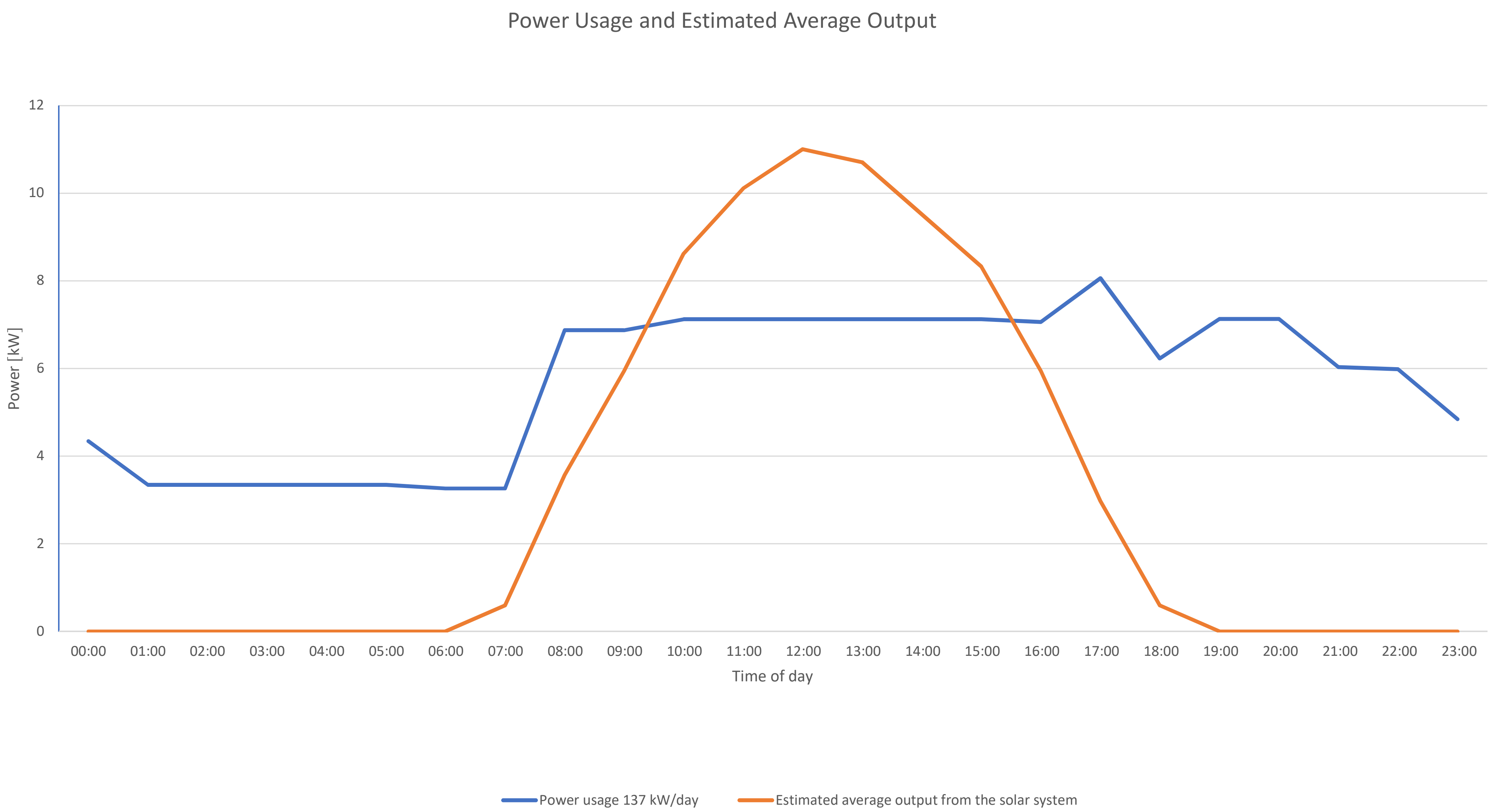
Year	MWh
0	29.28
1	28.4016
2	28.2027888
3	28.0053693
4	27.8093317
5	27.6146664
6	27.4213637
7	27.2294142
8	27.0388083
9	26.8495366
10	26.6615898
11	26.4749587
12	26.289634
13	26.1056066
14	25.9228673
15	25.7414073
16	25.5612174
17	25.3822889
18	25.2046129
19	25.0281806
20	24.8529833
Sum:	**561.078226**

Appendix C4

	Hour	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Sum [kW]	%
Power usage profile 137 kW/day	Wh	4342	3342	3342	3342	3342	3342	3262	3262	6874	6874	7124	7124	7124	7124	7124	7124	7062	8062	6230	7130	7130	6030	5982	4842		
Power usage profile 137 kW/day	kWh	4,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	6,9	6,9	7,1	7,1	7,1	7,1	7,1	7,1	7,1	8,1	6,2	7,1	7,1	6,0	6,0	4,8	137	
Power usage profile 360 kW/day	Wh	6933	5933	5933	5933	5933	5933	5853	5853	28846	28846	29096	29096	29096	29096	29096	29096	10878	11878	10046	10846	10846	8621	8573	7433		
Power usage profile 360 kW/day	kWh	6,9	5,9	5,9	5,9	5,9	5,9	5,9	5,9	28,8	28,8	29,1	29,1	29,1	29,1	29,1	29,1	10,9	11,9	10,0	10,8	10,8	8,6	8,6	7,4	360	
Daily horizontial irradiance at Rotifunk by hour	Wh/m2	0	0	0	0	0	0	0	50	300	500	725	850	925	900	800	700	500	250	50	0	0	0	0	0,0		
Estimated average output from the solar system	kWh	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	3,6	5,9	8,6	10,1	11,0	10,7	9,5	8,3	5,9	3,0	0,6	0,0	0,0	0,0	0,0	0,0	78	
Estimated output from the solar system in March	kWh	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,7	4,2	7,0	10,1	11,8	12,9	12,5	11,1	9,7	7,0	3,5	0,7	0,0	0,0	0,0	0,0	0,0	91	
Estimated output from the solar system in July	kWh	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	2,6	4,4	6,4	7,5	8,1	7,9	7,0	6,2	4,4	2,2	0,4	0,0	0,0	0,0	0,0	0,0	58	
Average missing/excess power	kWh	-4,3	-3,3	-3,3	-3,3	-3,3	-3,3	-3,3	-2,7	-3,3	-0,9	1,5	3,0	3,9	3,6	2,4	1,2	-1,1	-5,1	-5,6	-7,1	-7,1	-6,0	-6,0	-4,8		
Power need outside sun hours 137 kW/day	kWh	4	3	3	3	3	3	3	3										8	6	7	7	6	6	5	73	54
Power need inside sun hours 137 kW/day	kWh									7	7	7	7	7	7	7	7	7								64	47
Power need outside sun hours 360 kW/day	kWh	7	6	6	6	6	6	6	6										12	10	11	11	9	9	7	117	32
Power need inside sun hours 360 kW/day	kWh									29	29	29	29	29	29	29	29	11								243	68
Expected average output from the solar system including battery storage	kWh	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	3,6	5,9	7,1	7,1	7,1	7,1	7,1	7,1	7,1	8,1	6,2	3,1	0,0	0,0	0,0	0,0	77	
Added power from 4 kVA generator at 80%	kWh	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	59	
Estimated average output from the solar system including the 4 kVA generator	kWh	2,4	2,4	2,4	2,4	2,4	2,4	2,4	3,0	6,0	8,4	11,1	12,6	13,5	13,2	12,0	10,8	8,4	5,4	3,0	2,4	2,4	2,4	2,4	2,4	137	
Missing/excess power including the 4 kVA generator	kWh	-1,9	-0,9	-0,9	-0,9	-0,9	-0,9	-0,8	-0,2	-0,9	1,5	4,0	5,4	6,3	6,0	4,8	3,7	1,3	-2,6	-3,2	-4,7	-4,7	-3,6	-3,5	-2,4	0	
Estimated average output from the PV system including battery storage and 4kVA generator	kWh	4,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4	7,0	7,0	7,2	7,2	7,2	7,2	7,2	7,2	7,2	8,2	6,3	7,2	7,2	6,1	6,1	4,9		

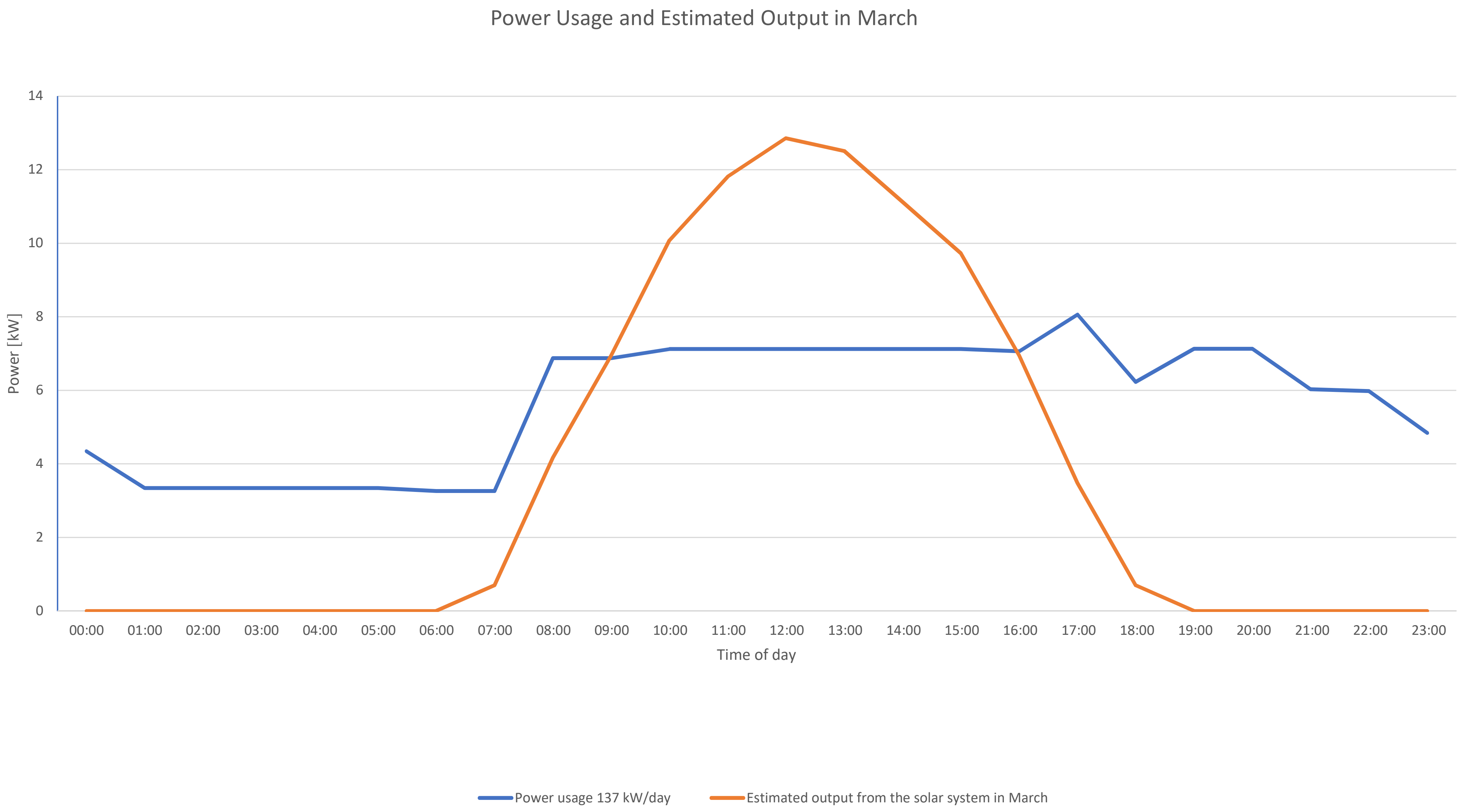
Estimated output from the PV system = Irradiance in kW$\times 131 m^2 \times 0{,}153 \times 0{,}886 \times 0{,}67$

Appendix C5



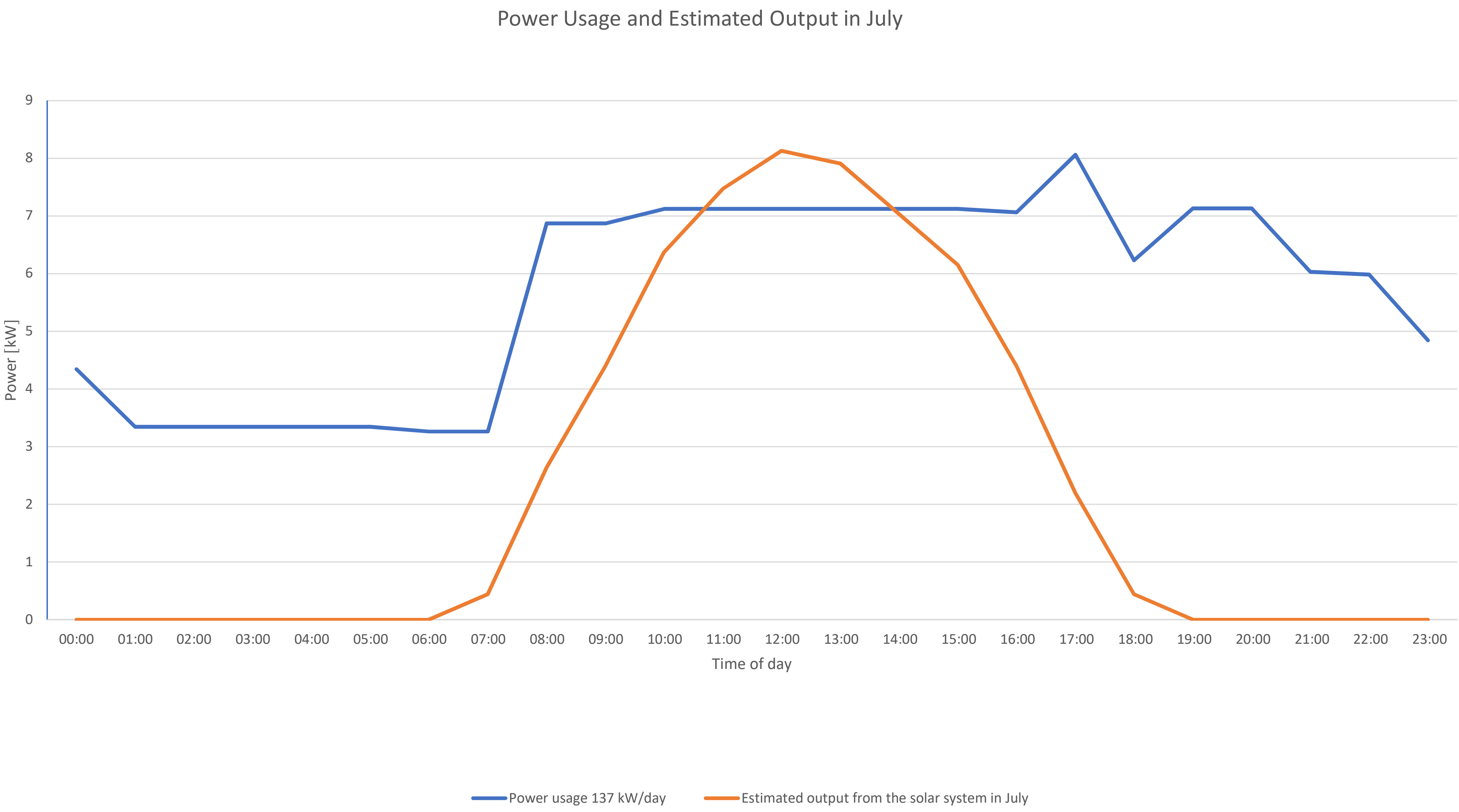
Power Usage and Estimated Average Output
Power [kW]
12
10
8
6
4
2
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of day
Power usage 137 kW/day
Estimated average output from the solar system

Appendix C6



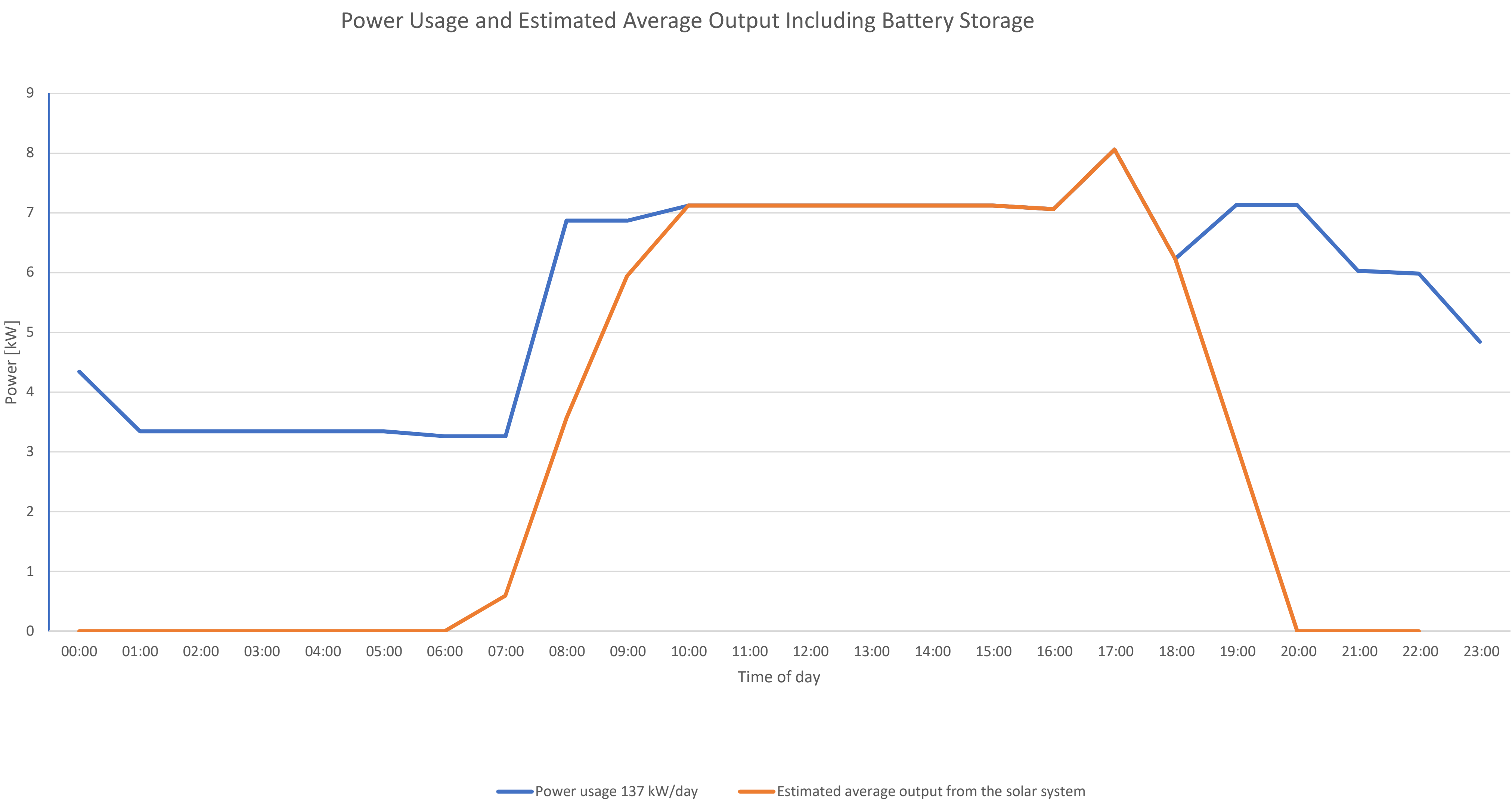
Power Usage and Estimated Output in March
Power [kW]
14
12
10
8
6
4
2
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of day
Power usage 137 kW/day
Estimated output from the solar system in March

Appendix C7



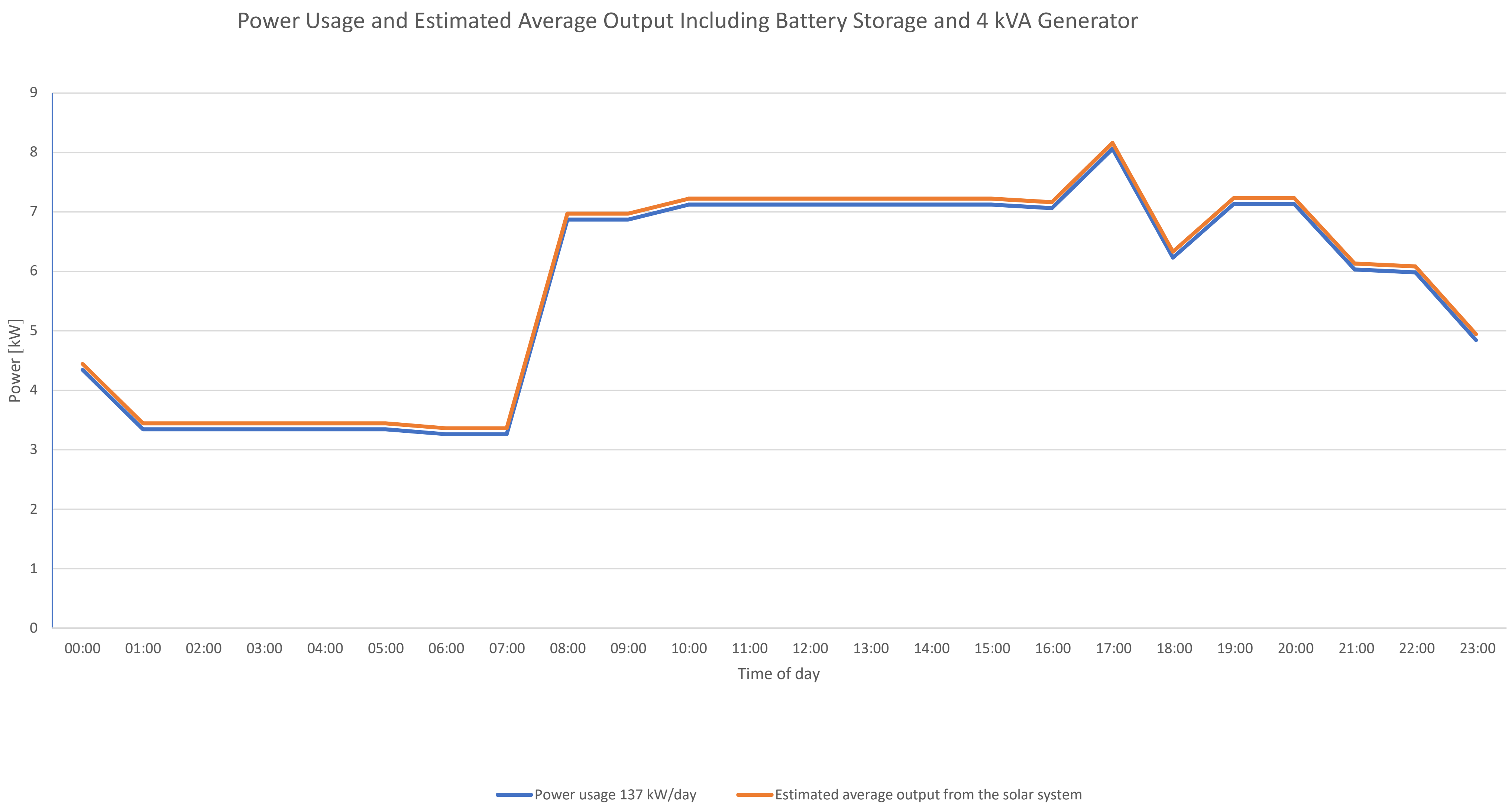
Power Usage and Estimated Output in July
Power [kW]
0
1
2
3
4
5
6
7
8
9
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of day
Power usage 137 kW/day
Estimated output from the solar system in July

Appendix C8



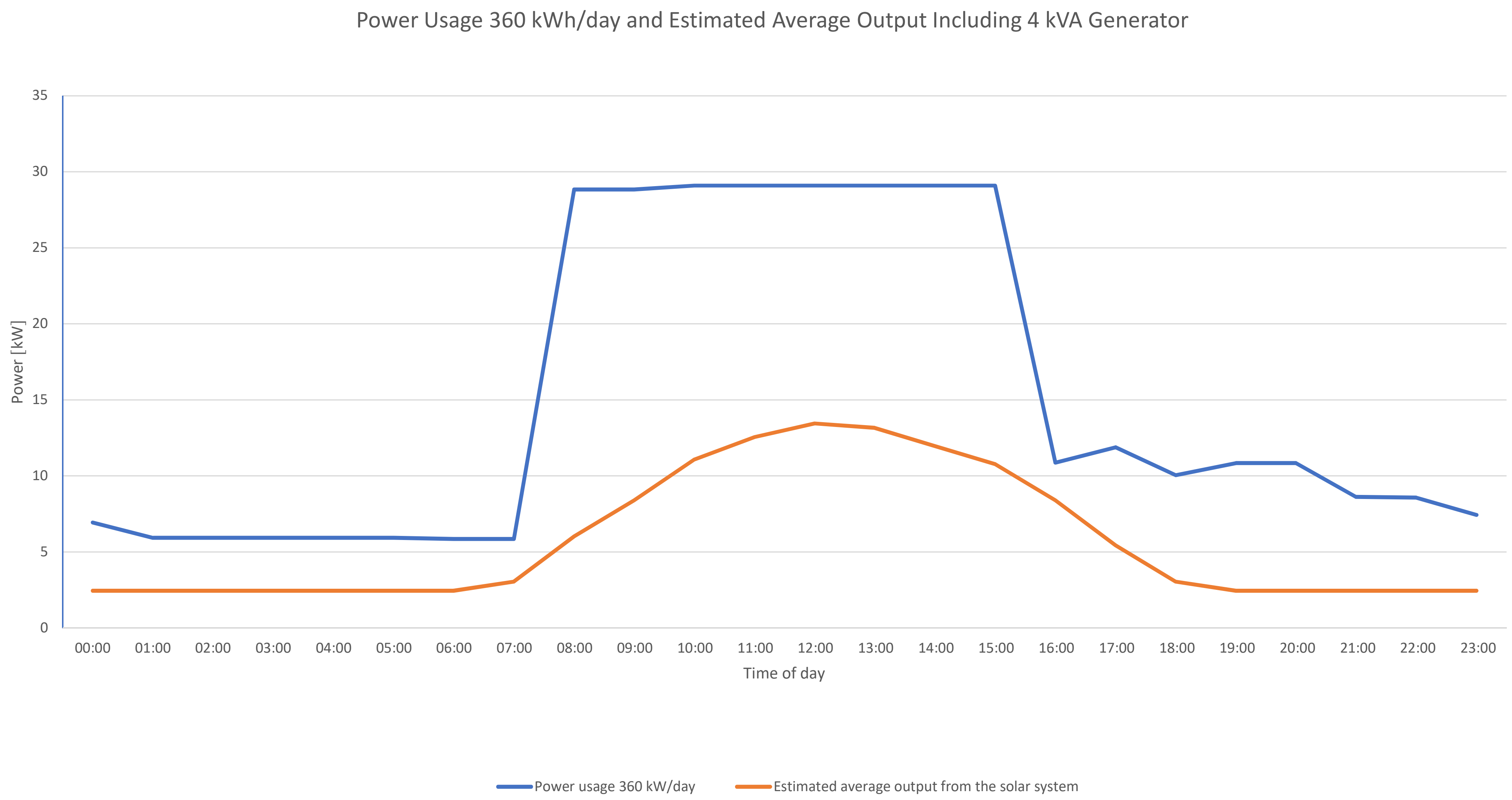
Power Usage and Estimated Average Output Including Battery Storage
Power [kW]
9
8
7
6
5
4
3
2
1
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of day
Power usage 137 kW/day
Estimated average output from the solar system

Appendix C9



Power Usage and Estimated Average Output Including Battery Storage and 4 kVA Generator
Power [kW]
9
8
7
6
5
4
3
2
1
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of day
Power usage 137 kW/day
Estimated average output from the solar system

Appendix C10

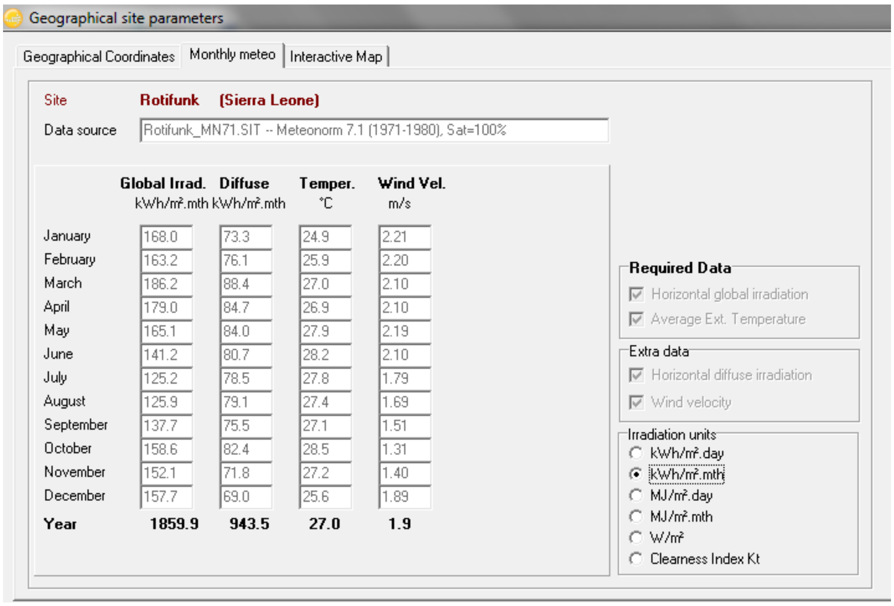


Appendix D

Sola Irradiance Data at Rotifunk

Data downloaded from the PVsyst Program`s meteo database.

Figure D.1 - Geographical Site Parameters in Rotifunk



Geographical site parameters

Geographical Coordinates | Monthly meteo | Interactive Map

Site: **Rotifunk (Sierra Leone)**

Data source: Rotifunk_MN71.SIT -- Meteonorm 7.1 (1971-1980), Sat=100%

	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	168.0	73.3	24.9	2.21
February	163.2	76.1	25.9	2.20
March	186.2	88.4	27.0	2.10
April	179.0	84.7	26.9	2.10
May	165.1	84.0	27.9	2.19
June	141.2	80.7	28.2	2.10
July	125.2	78.5	27.8	1.79
August	125.9	79.1	27.4	1.69
September	137.7	75.5	27.1	1.51
October	158.6	82.4	28.5	1.31
November	152.1	71.8	27.2	1.40
December	157.7	69.0	25.6	1.89
Year	**1859.9**	**943.5**	**27.0**	**1.9**

Required Data
- Horizontal global irradiation
- Average Ext. Temperature

Extra data
- Horizontal diffuse irradiation
- Wind velocity

Irradiation units
- kWh/m².day
- kWh/m².mth
- MJ/m².day
- MJ/m².mth
- W/m²
- Clearness Index Kt

Figure D.2 - Daily Horizontial Irradiance by Hour

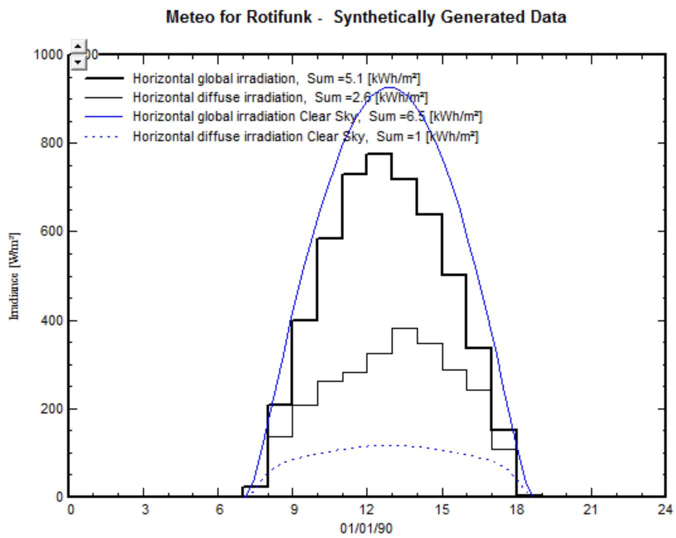
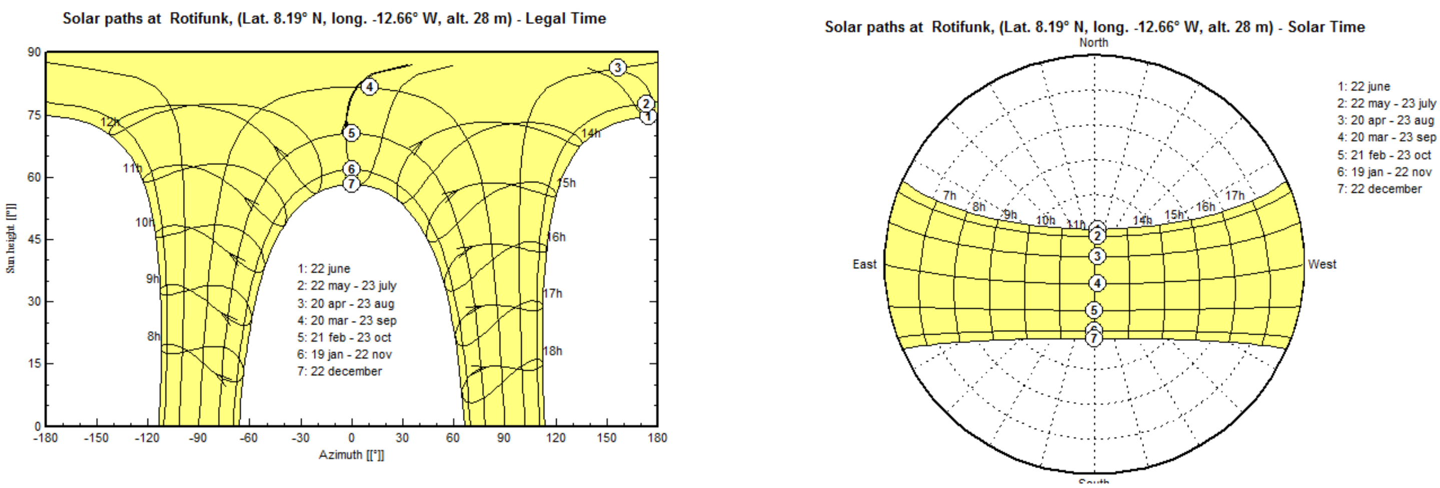
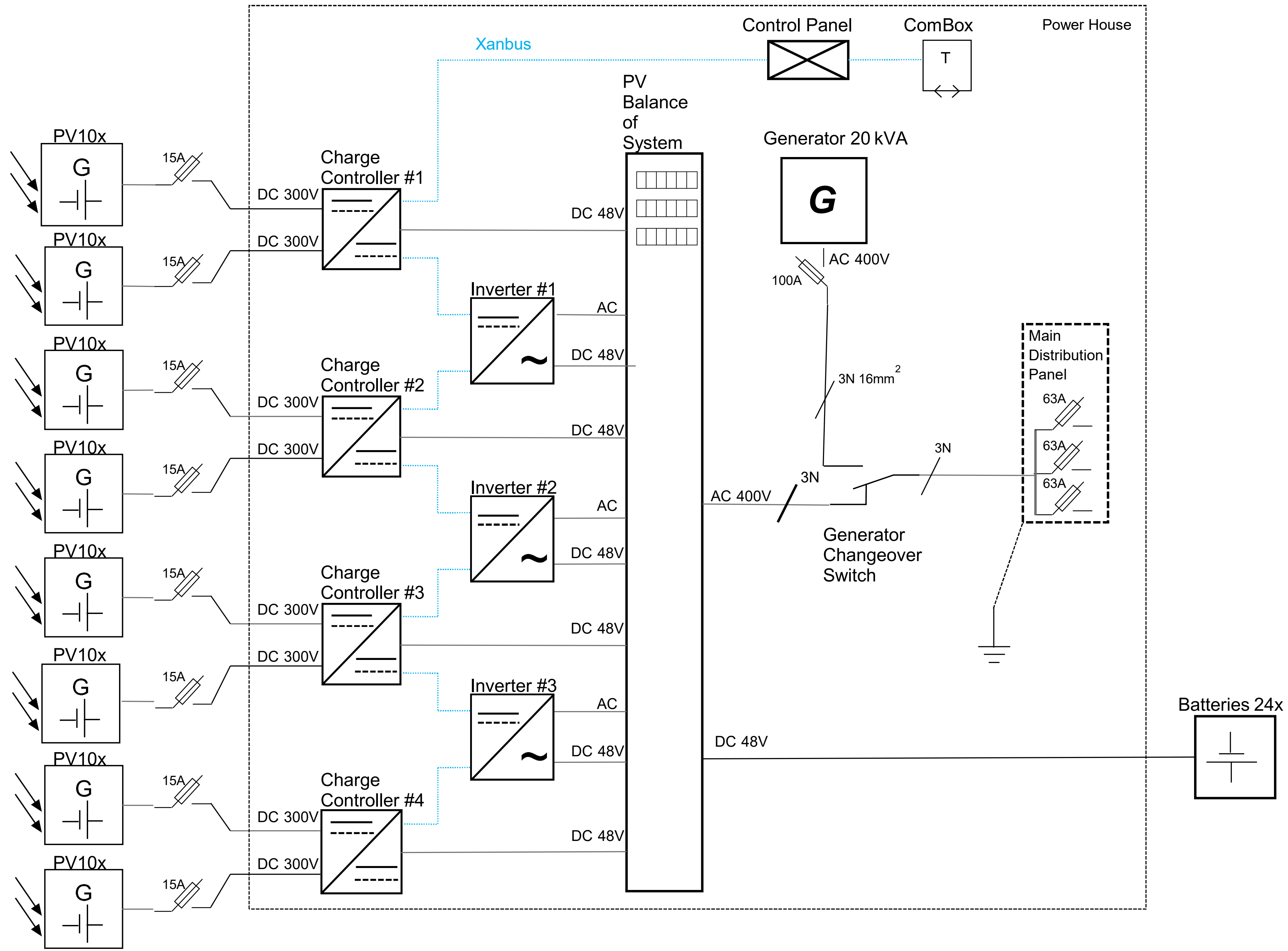


Figure D.3 - Solar Paths Throughout the Year

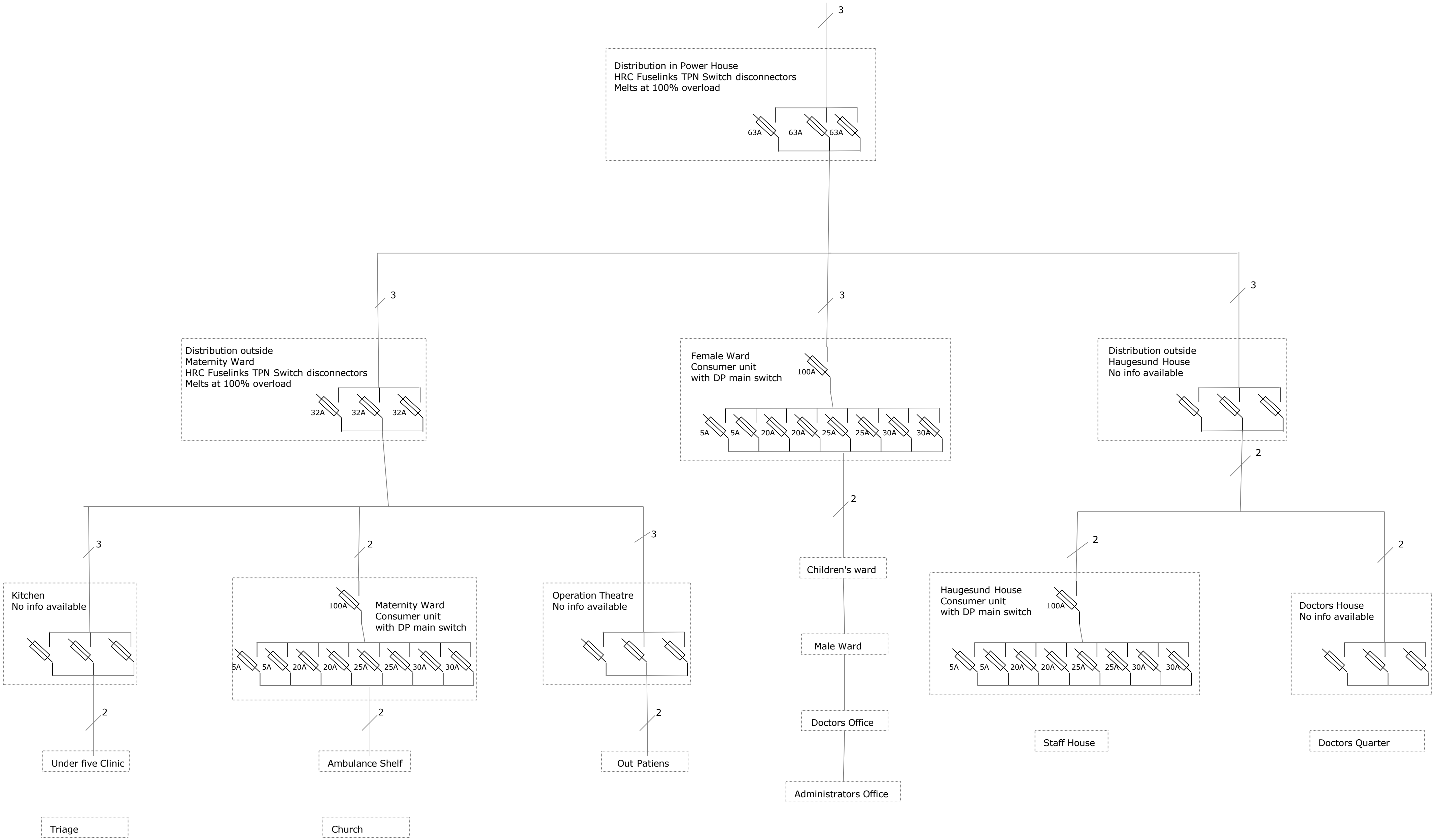


Appendix E1



Power House
Control Panel
ComBox
T
Xanbus
PV Balance of System
Generator 20 kVA
G
AC 400V
100A
3N 16mm^2
Main Distribution Panel
63A
63A
63A
3N
3N
AC 400V
Generator Changeover Switch
PV10x
G
15A
Charge Controller #1
Charge Controller #2
Charge Controller #3
Charge Controller #4
DC 300V
DC 48V
Inverter #1
Inverter #2
Inverter #3
AC
DC 48V
Batteries 24x

Appendix E2


3
Distribution in Power House
HRC Fuselinks TPN Switch disconnectors
Melts at 100% overload
63A
63A
63A
3
3
3
Distribution outside
Maternity Ward
HRC Fuselinks TPN Switch disconnectors
Melts at 100% overload
32A
32A
32A
Female Ward
Consumer unit
with DP main switch
100A
5A
5A
20A
20A
25A
25A
30A
30A
Distribution outside
Haugesund House
No info available
2
2
3
2
3
2
2
Kitchen
No info available
100A
Maternity Ward
Consumer unit
with DP main switch
5A
5A
20A
20A
25A
25A
30A
30A
Operation Theatre
No info available
Children's ward
Haugesund House
Consumer unit
with DP main switch
100A
5A
5A
20A
20A
25A
25A
30A
30A
Doctors House
No info available
Male Ward
2
2
2
Doctors Office
Staff House
Doctors Quarter
Under five Clinic
Ambulance Shelf
Out Patiens
Administrators Office
Triage
Church

Appendix F

Quote #	
Date	

From:	**To:**
Energy For Opportunity 95D Regent Rd, Lumley, Freetown Sierra Leone +232 76 692155	

Item No.	Quantity	Description	Unit	Unit Price	Total
Direct Payment to Suppliers					
1	24	Deep Cycle Battery	Ea	1100	26,400
2	3	Inverter/Charger --- 6800W	Ea	2673	8,019
3	4	Charge Controller --- 600V/80A	Ea	1117	4,466
4	14	Lightning Arrestor	Ea	96	1,344
5	1	PV Balance of System	Set	3407	3,407
6	1	Xantrex Control Panel	Ea	226	226
7	1	Xantex ComBox	Ea	259	259
8	1	Electrical Items - Solar	Set	3042	3,042
9	1	Transportation --- International	Ea	6,000	6,000
Transfer to Sierra Leone					
10	1	Import Duty and GST	Ea	9432	9,432
11	80	Module - 250W	Ea	242	19,360
12	4	AVS - 5kW	Ea	150	600
13	1	Mounting Fixture (aluminum with stainless steel bolts)	Ea	3064	3,064
14a	1	Battery Enclosure and Cover	Ea	1310	1,310
14b	1	Air Conditioner - 9000BTU	Ea	650	650
15	1	Array Perimeter Fence (Mesh with block foundation)	Ea	3179	3,179
16	1	Electrical Items - Building and Grounding	Set	11202	11,202
17	1	Installation and labour	Ea	14950	14,950
18	1	Transportation --- Domestic	Ea	1,680	1,680

Notes:
1) Electrical Items - Building and Grounding includes 100 pieces of LED bulbs
2) Import Duty and GST to be paid upon presentation of receipts; duty free importation will be attempted

Sub-total	118588
WHT / GST	0
Total	$118,588

Terms:
- Quote is valid for 30 days
- Installation timing: 12-16 weeks
- Equipment fees apply to cancelled orders
- Balance payment must be received within 30 days of invoice
- Interest to be charged at 20% APR to all overdue accounts
- Payment to made in $US or Leones through cheque or bank transfer

Appendix G

Foreningen Haugesund Rotifunk

Technical Assessment Report

Hatfield Archer Memorial Hospital

Description and assessment of the electrical installations at the hospital.

1	??.07.16	For comments	A. Lie			
Rev.	**Date**	**Description**	**Made by**	**Chk'd by**	**Appr.**	**Appr.**
			Originator			**Client**

INGENIØRER UTEN GRENSER

		Document title: Description and assessment of the electrical installations at the hospital.	
Area:	Sierra Leone	**Document Number:**	**Rev. 1**
System:	Electrical	P001-HG-E-001	
Doc. Type:	Technical Report	**Project – Origin. – Disc. - Sequence**	

Appendix G

Table of contents

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1 Summary.

Skrives helt til slutt.

2 Introduction

2.1 General

The purpose of this report is to

- Describe the electrical system at the Hatfield Archer Memorial Hospital.
- Describe the current state of the electrical installations.
- Suggest required modifications to ensure the electrical system will be functioning when the new solar power system is installed.

Haugesund Rotifunk has decided to use a local Sierra Leona company, Energy For Opportunities (EFO), to provide and install the solar plant. EFO will also inspect in detail the state of the current electrical installations.

For this reason, the IUG team decided not to give priority to detailed investigation of the installations in each building; but to document the overall installations and to identify the most important electrical consumers. This will form the design basis when sizing the solar plant.

EFO was represented in during the site visit with one electrician:

Name:	Alusine Henry Thorpe
e-mail:	AlusineThorpe@gmail.com
Phone:	(+232) 076-256-065
	(+232) 077-223-925

The IUG team consisted of IUG-members Rune Hetlelid, Ben Knutsen and Asbjørn Lie.

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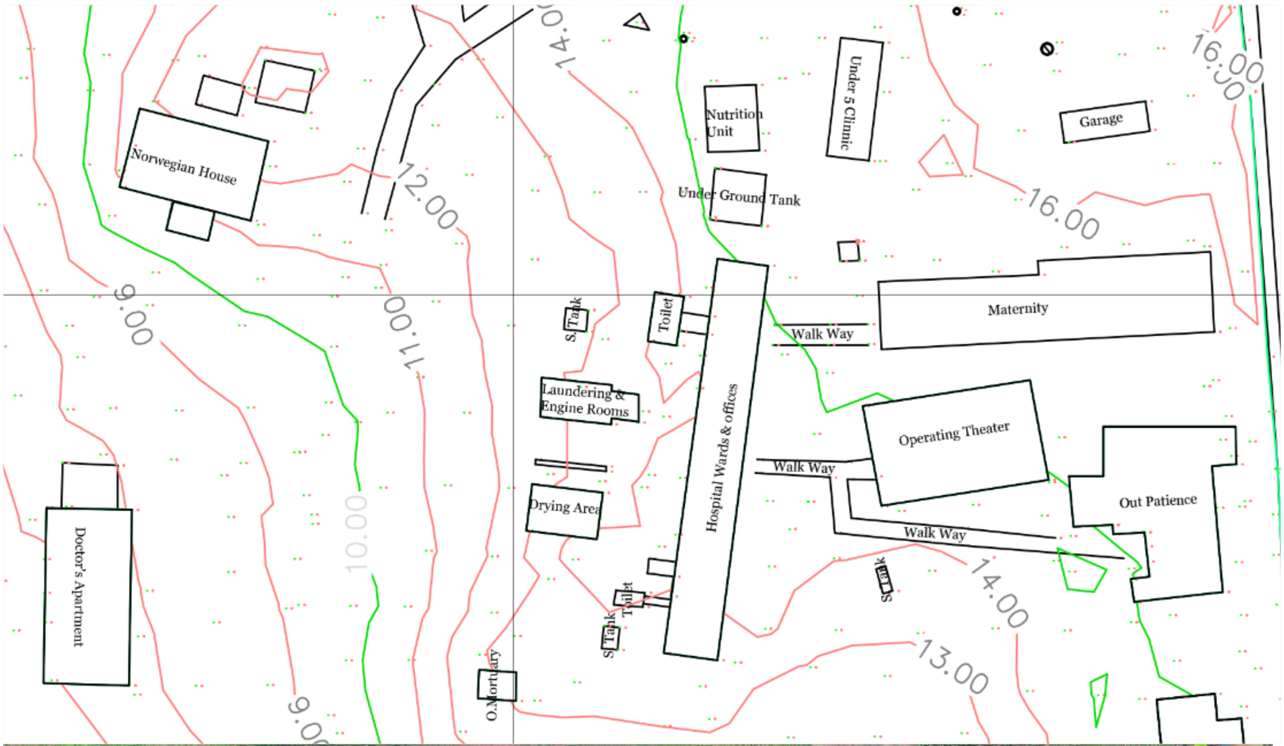
3 Site overview



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4 Electrical system description

Installation is assumed to comply with utilisation category AC 22A (According to British Standards - BS EN 60947-3)

4.1 Wire color coding

Mostly based on the deprecated british standard (L1: Red, L2: Yellow, L3: Blue, N: Black). Some power cables used the european color coded wires, but not according to specification (L1: Brown, L2: Gray, N: Black)

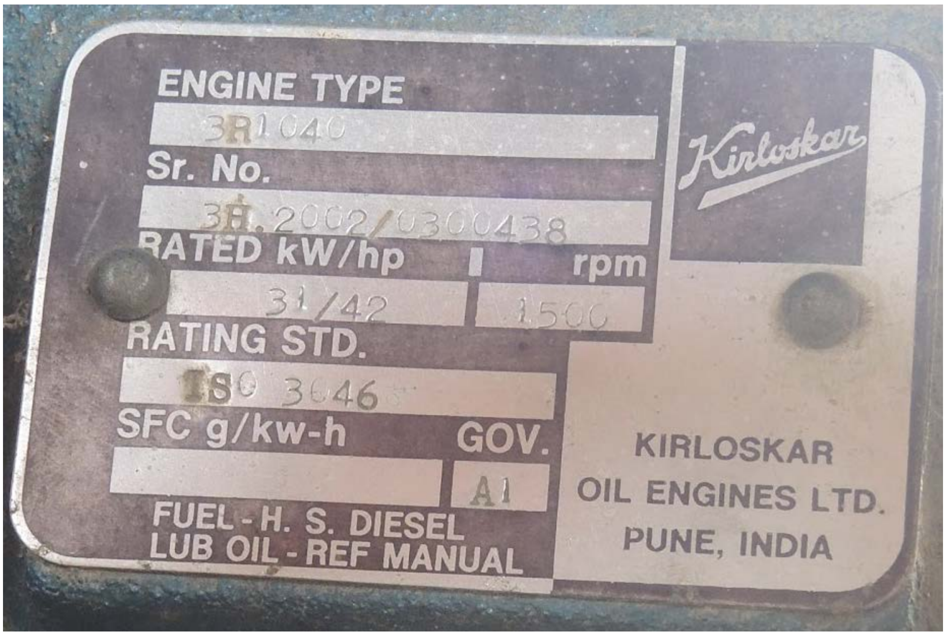
4.2 Power generation

4.2.1 Existing 20 kW generator.

Alternator
The windings of this generators have been damaged, and it has been several months in Freetown for rewinding. Only the diesel engine and frame was in the generator building at time of inspection.

Engine
Technical specifications: http://stechengg.com/download/Catalogue%20R1040%20.pdf

Appendix G



4.2.2 New 4 kW generator

A new 4 kW diesel driver generator was purchased and installed during the trip.

SDMO Diesel 4000 E XL C, http://www.sdmo.com/EN/Products/PPW/Portable-power-generators/Diesel/DIESEL-4000-E-XL-C

4.2.3 Promised new 20 kW generator.

During a meeting with the Bishop 25.6.16, he informed that an organisation has decided to buy a new 25 kVA Lister driven generator and to donate it to the hospital in Rotifunk. No more technical data available. Delivery time 2-3 months.

He will also connect Haugesund Rotifunk to this organisation to exchange technical information, as it needs to be integrated into the new solar power system.

4.3 Electrical network description.

The existing 20 kW kVA generator was delivering 3-phase 400V (TN-network) to the main switches and distribution boards.

Appendix G

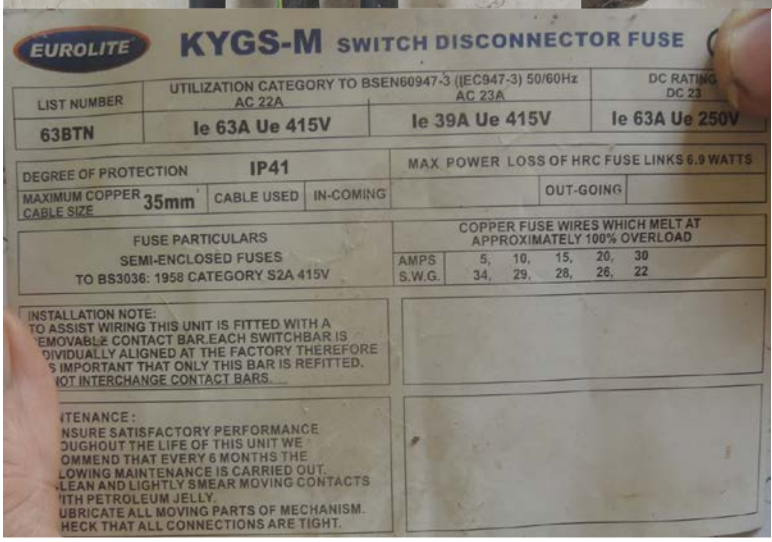
The new 4 kW generator is delivering 1-phase, so parts of the existing network had to be disconnected and reconnect to enable the new generator to supply the network with electricity.

This may have to be reversed when the new 25 kVA generator is installed.

The cables and connections of the original network is shown schematically in the single-line diagram (attachment A) and the cable list (attachment B). Details of electrical consumers per building and room is described below, and summarized in the spreadsheet in attachment C.

4.3.1 *Generator room switchboard.*

This box is distributing 3-phase to 3 other boxes; Female Ward, box outside Maternity Ward (H03?) and box outside Haugesund House.
MEM EXEL 2 63A HRC Fuselinks TPN switch-disconnector-fuses



4.3.2 *Female Ward.*

Memguard consumer unit (CU8F) with a 100A DP main isolator switch (SW250R)

Appendix G

This distribution board is also distributing electricity to Children’s ward, Male ward, Doctors Office and Administrators Office.

Common outside areas contain the following electrical consumers:

- 4 fluorescent tubes, 18 Watts each.
- 12 LED light bulbs, typically 9 Watts.

Female Ward contains the following electrical consumers:

- 7 fluorescent tubes, 36 Watts each.
- 3 fans.
- 2 LED light bulbs, typically 9 Watts.

Children’s ward contains the following electrical consumers:

- 2 fluorescent tubes, 36 Watts each.
- 1 fan.

Male ward contains the following electrical consumers:

- 7 fluorescent tubes, 36 Watts each.
- 3 fans.
- 2 LED light bulbs, typically 9 Watts.

Doctors Office contains the following electrical consumers:

- 1 fluorescent tube, 36 Watts each.
- 1 Westpoint A/C unit, 1250 Watt.

Administrators Office contains the following electrical consumers:

- 1 fluorescent tube, 36 Watts each.

4.3.3 Switchgear box outside maternity ward, H03?

This is supplying 1-phase to the Maternity distribution board, 3-phase to Operation Theatre fuseboard, and to the kitchen distribution board.

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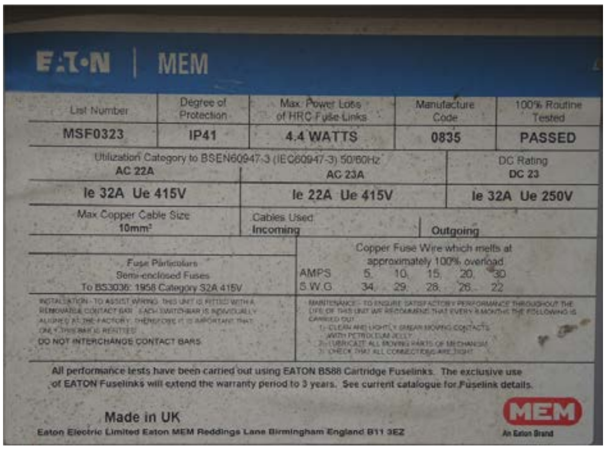
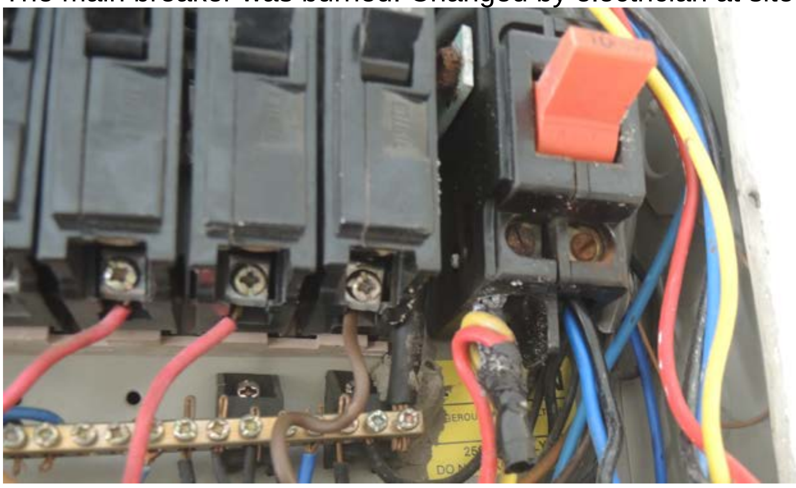


4.3.3.1 Maternity Ward

The main breaker was burned. Changed by electrician at site.



The building contains the following electrical consumers:

- 16 fluorescent tubes, 36 Watts each. Inkluderer dette 4 ute?
- 7 fans.
- 2 LED light bulbs, typically 9 Watts.
- 1 JSK A/C unit, 1880 Watt.

BILDE

4.3.3.2 Operations Theatres

Nurses change room/entrance contains the following electrical consumers:

- 1 fluorescent tube, 36 Watts each.
- 1 fan.
- 3 LED light bulbs, typically 9 Watts.

Matron’s Office contains the following electrical consumers:

- 1 fan.
- 1 LED light bulbs, typically 9 Watts.

Stores room contains the following electrical consumers:

- 1 fluorescent tube, 36 Watts each.

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Operation Theatre 1 contains the following electrical consumers:
- 4 fluorescent tube, 36 Watts each.
- 2 JSK A/C units, 1880 Watts each.
- 1 operation light, ? Watt.
- 1 operation table, ? Watt.

Operation Theatre 2 contains the following electrical consumers:
- 4 fluorescent tube, 36 Watts each.
- 1 JSK A/C unit, 1880 Watt.
- 1 operation light, ? Watt.
- 1 operation table,? Watt.

Recovery Ward contains the following electrical consumers:
- 1 fluorescent tube, 36 Watts each.
- 1 Westpoint A/C unit, 1250 Watt.
- 2 LED light bulbs, typically 9 Watts.

Kitchen distribution panel distribute electricity to the kitchen and to the under 5 clinic.

The kitchen contains the following electrical consumers:
- 1 fluorescent tube, 36 Watts each.
- 3 LED light bulbs, typically 9 Watts.

Under 5 clinic contains the following electrical consumers:
- 4 fluorescent tubes, 36 Watts each.
- 2 LED light bulbs, typically 9 Watts.

The Operation Theatre distribution board also distribute electricity to the out-patient buildings.

Out-patient buildings contain the following electrical consumers:
- 6 fluorescent tubes, 36 Watts each.
- 5 fans
- 1 JSK A/C unit, 1880 Watt in CHO office
- 1 JSK A/C unit, 1880 Watt in drug store
- 1 JSK A/C unit, 1880 Watt in pharmacy
- 11 LED light bulbs, typically 9 Watts.

Church is not connected to network.

The new Triage building is not connected to the network.

4.3.4 Switchgear box outside Haugesund House.

This is supplying 1-phase to Haugesund House distribution board, and to the Doctors House fusepanel.

The main switch is not functioning and must be repaired or replaced.

BILDE

Haugesund House contains the following electrical consumers (H06?) :
- 2 fluorescent tubes, 36 Watts each.
- 1 fluorescent tubes, 18 Watts each.

- 2 fans
- 9 LED light bulbs, typically 9 Watts.
- 1 refrigerator, 140 Watt, 1.13 kW/24 hrs

The panel consists of one 100A switch (not connected, and removed during the assessment period), and 8 fuses in the range 5A to 30A. Cables are 2.5 mm^2.

Doctor's House contains the following electrical consumers:
- 6 fluorescent tubes, 36 Watts each.
- 1 JSK A/C unit, 1880
- 4 LED light bulbs, typically 9 Watts.

Staff House contains the following electrical consumers:
- 14 LED light bulbs, typically 9 Watts.

Nurses Quarter contain no electrical network or equipment.

4.4 Haugesund House internal +H06

Main switch not connected

4.5 Earthing.

The earth cable in the generator room is connected to a metal rod, close to the wall (white cable on picture below).

Appendix G

5 Electrical system state.

5.1 Generators

5.1.1 Existing 20 kW generator.

The alternator is still in Freetown for repair. It appears that the generator has not been working since October 2015, and even during the years before that, reliability was low.

UMC has been promised a new replacement generator (ref. 4.1.3), and this non-working generator is most likely to be scrapped.

5.1.2 New 4 kW generator

The new 4 kW diesel driver generator is working fine; and one local operator has been trained to start and stop the unit. He has also been instructed how to do the basic maintenance; but this require follow-up to verify that it is done at correct intervals. Lube oil, filters etc has been delivered and is stored with the generator.

The paper copy of the Operating and Maintenance Manual was left with the local operator; and electronic pdf-copy has been ordered from the manufacturer.

The key required to use the electric starter was lost before handover of the generator; a new should be ordered from the local supplier in Freetown.

In the meantime, the unit is started manually.

As this is a 1-phase generator, re-cabling was required to enable the generator to supply the original 3-phase/1-phase network. More info ref. 3.2.

5.1.3 Promised new 20 kW generator.

No technical data available, no information regarding contact persons in the organisation providing the generator is available.

5.1.4 New solar power generation system.

IUG team and EFO electrician suggest to use the current generator building as a battery and control room.

The existing 20 kW generator to be removed and scrapped. The existing 4 kW generator and the future new 25 kVA generator must be located in another building.

We suggest these two alternatives:

- Build a new generator house close to the existing generator house.
- Use the old generator house, about 50 m south of the present generator house.

Final decision depends upon UMC's new General Plan for the Rotifunk hospital.

Appendix G

5.2 Network

5.2.1 Earthing system.

Measurement of voltage to earth was done by using the spare outlet from the 4 kW 1-phase generator.

The reading show 192 V between one phase and earth, and 34 V between the other phase and earth. Recommended values are > 100 V.

We also poured a bucket of water and waited to see if increased moisture in the ground would make a change, but values did not change much.

<u>Conclusion:</u> The present earthing system is not acceptable, and should be replaced by a new.

5.2.2 Ground cables

Most cables in the ground are of good quality and in a good state and can be reused.

The following work is required:

- Ground cable from Haugesund House to Doctor's House is damaged by fire, and require a total changeout.
- Unable to locate any ground cable to staff house. Will most likely require a new cable to be installed from Haugesund House.
- Unable to locate a cable to the new Triage building. New cable required.
- No cables installed to the Church. New cable required.

5.2.3 Connections in boxes/fuse panels

All connections in the switchboxes H0?, H06, H0? Were removed due to following reason:

- Colour coding of cables not consistent.
- Rebuilding the net to a straight 1-phase net due to new 1-phase 4 kW generator.
- Unsure about earth faults, short circuits etc, and wanted to isolate as much of the net from been energized when we connected electricity to the prioritized buildings (maternity ward and operation theatre 2).

Depending upon the design of the solar system, parts of this works has to be reversed when connecting to the new solar system.

5.2.4 Buildings

5.2.4.1 Store room in out-patient area.

This is to be converted to laboratory; and should have an A/C unit.

5.2.4.2 Office in out-patient area.

This is to be converted to pharmacy, and should have an A/C unit.

5.2.4.3 Church

There are some light sockets, but in a bad state. Suggest to remove all electrical installation, and reinstall properly. To include some light, and sockets suitable for PA units. Cables to be sized for 16/20 A, but fuse may limit consumption to 6A if short of electricity.

5.2.4.4 Triage.

Not connected to rest of electrical network. Suggest it should be connected either directly to maternity switchboard, or indirectly via the kitchen/under 5 cable.

5.2.4.5 Nurse quarter.

No electrical installation now, suggest to include electrical installations in this building in the next phase.

5.3 Medical equipment.

5.3.1 Ultrasound equipment

The model 3535 ultrasound apparatus in maternity ward was tested, and appeared to be working.

The model 3535 ultrasound apparatus in CHO's was not tested.

The 2 models 3535 ultrasound apparatus in operation theatres ward were tested, and 1 appeared to be working, the other was not working.

Power consumption for the model 3535 ultrasound apparatus is 800-1200 VA.

Another ultrasound apparatus located in operation theatre 2 was tested, and appeared to be working.

BILDER?

5.3.2 Autoclave.

2 Getinge Autoclaves SAB 2213 were located outside the operation theatres; still in their wooden boxes used when they were sent in 1986. They require permanent hook-up to water in/out in addition to electricity.

BILDER?

6 Conclusions and recommendations

Skrives til slutt:

Earthing.

Ground cables.

Connections.

Inhouse cabling.

Entire electrical installation should be reviewed according to local requirements. ENFO is performing a separate detailed assessment of the installation.

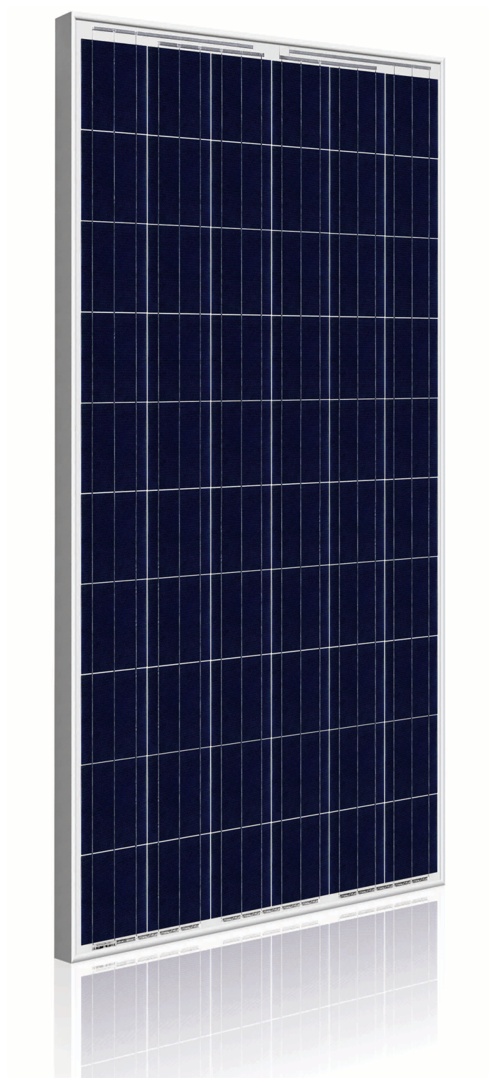
7 ATTACHMENTS

A Single-line diagram (Ben)
B Cables list (Ben)
C Expected electrical consumption spreadsheet (Ben)

HSC 60 Poly Can-Am

Hanwha Solar

Made in Ontario, Canada



Five Key Features

1 **Highly Bankable**
Proven field performance with strong company financials

2 **Industry-Leading Warranty**
12 year workmanship warranty, 25 year linear performance warranty*

3 **Positive Power Sorting**
Predictable output of 0 to +5W

4 **Robust Design**
Certified to withstand high snow loads, up to 5400 Pa**, and available for 600V or 1000V applications.

5 **Made in Ontario**
Reliable solar modules that meet domestic content requirements

* Please refer to Hanwha Solar Canada Inc Product Warranty for details.
** Please refer to Hanwha Solar Canada Inc module Installation Guide.

Quality and Environmental Certificates

- ISO9001 quality standards and ISO 14001 environmental standards
- ETL Certified to UL 1703/ULC ORD C1703 (1000V) for use in US and Canada

About Hanwha Solar

Hanwha SolarOne, Hanwha Solar Canada's parent is a vertically integrated manufacturer of photovoltaic modules designed to meet the needs of the global energy consumer.

- High reliability, guaranteed quality, and excellent cost-efficiency due to vertically integrated production and control of the supply chain;
- Optimization of product performance and manufacturing processes through a strong commitment to research and development;
- Global presence throughout Europe, North America, and Asia, offering regional technical and sales support.

Appendix H1

HSC 60 Poly Can-Am

Electrical Characteristics

Electrical Characteristics at Standard Test Conditions (STC)

Power Class	245 W	250 W	255 W	260 W	265 W
Maximum Power (P_{max})	245 W	250 W	255 W	260 W	265 W
Open Circuit Voltage (V_{oc})	37.7V	37.9V	38.1 V	38.3 V	38.5 V
Short Circuit Current (I_{sc})	8.65 A	8.76 A	8.88 A	9.01 A	9.12 A
Voltage at Maximum Power (V_{mpp})	30.2 V	30.4 V	30.6 V	30.8 V	31.0 V
Current at Maximum Power (I_{mpp})	8.11 A	8.22 A	8.33 A	8.44 A	8.55 A
Module Efficiency	15.0 %	15.3 %	15.6 %	15.9 %	16.2 %

P_{max}, V_{oc}, I_{sc}, V_{mpp}, and I_{mpp} tested at STC defined as irradiance of 1000 W/m² at AM 1.5 solar spectrum and temperature 25 ± 2°C.
Electrical Characteristics: Measurement tolerance of ± 3%.

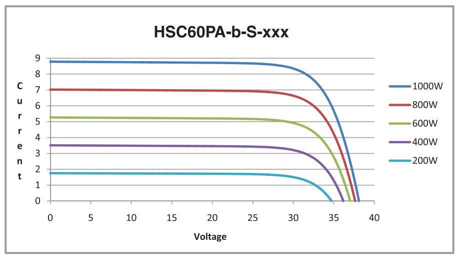
Nomenclature

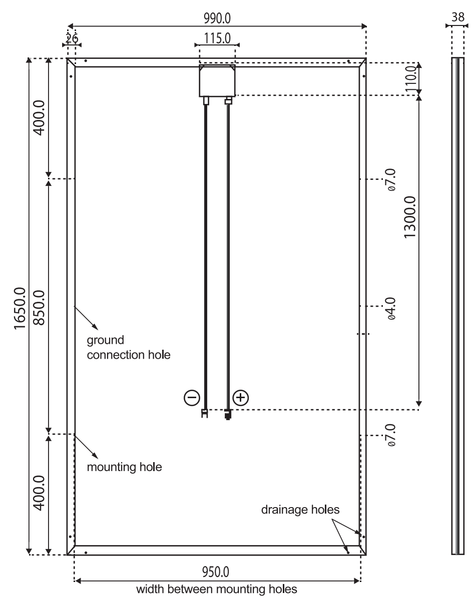
Full product name:
HSC60Pa-b-c-xxx
Where a is the module grade (A-Z), and b and c represent module generations (A-Z)

xxx represents the power class

Performance at Low Irradiance:

The typical relative change in module efficiency at an irradiance of 200 W/m² in relation to 1000 W/m² (both at 25°C and AM 1.5 spectrum) is less than 5%.





Temperature Characteristics

Normal Operating Cell Temperature (NOCT)	45°C ±3°C
Temperature Coefficients of P	–0.40%/°C
Temperature Coefficients of V	–0.34%/°C
Temperature Coefficients of I	+0.06%/°C

Maximum Ratings

Maximum System Voltage	600V or 1000 V
Series Fuse Rating	15 A
Maximum Reverse Current	Series fuse rating multiplied by 1.35

Mechanical Characteristics

Dimensions	1650mm x 990mm x 38mm (64.96in x 38.98in x 1.5in)
Weight	19 kg (41.9 lbs)
Frame	Aluminum alloy
Front	AR Coated Tempered Glass
Encapsulant	EVA
Back Cover	Composite sheet
Cell Technology	Polycrystalline
Cell Size	156mm x 156mm (6in x 6in)
Number of Cells (Pieces)	60 (6 x 10)
Junction Box	Protection class IP65 with bypass-diode
Output Cables	Solar cable: 4mm²; length 1300mm (51.2in)
Connector Type	MC4 Comparable

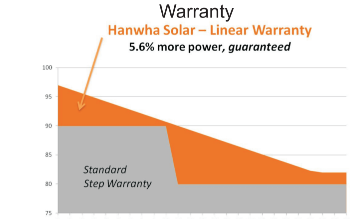
System Design

Operating Temperature	–40°C to 85°C
Hail Safety Impact Velocity	25mm at 23m/s
Fire Safety Classification (IEC) 61730	Class C
Static Load Wind/Snow	2400 Pa/5400Pa

Packaging and Storage

Storage Temperature	–40°C to 85°C
Packaging Configuration	35 modules per pallet
Loading Capacity (53 ft. Trailer)	630 modules

Warranty



Hanwha Solar
canadasales@hanwha-solarone.com
www.hanwhasolarcanada.com
wwww.hanwha-solarone.com
2860 Innovation Drive, London, Ontario, N6M 0C5 (519) 457-8325

Appendix H2

S2-3220GEL

2V 3220 AH @C20

TUBULAR POSITIVE - OPzV - VALVE REGULATED GEL BATTERY

Certified System
SAI GLOBAL
ISO 9001
Quality

BATTERY ENGINEERING
BY SURRETTE BATTERY COMPANY

CONSTANT CURRENT DISCHARGE

CUT OFF VOLTAGE V/CELL	30M	1HR	2HR	3HR	5HR	6HR	8HR	10HR	20HR
1.6V	2775	1896	1149	825	531	477	364	315	165

SPECIFICATIONS

Nominal Voltage		2 Volt
Rated Capacity (20 hour rate)		3220 AH
Dimensions	Total Height (including terminals)	807mm / 31.77"
	Length	576mm / 22.68"
	Width	212mm / 8.35"
	Weight	496.04 lbs / 225.0 Kg

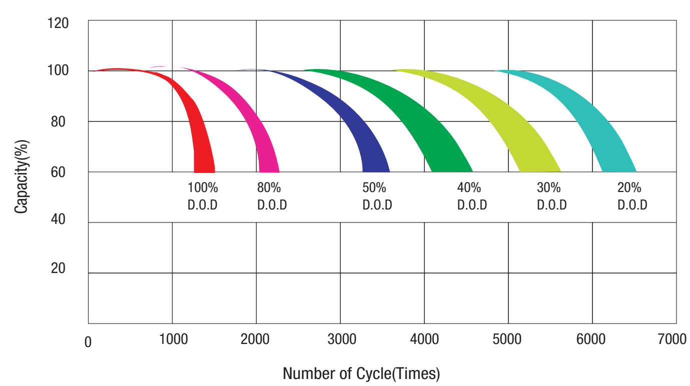
MH28539

G4M20206-0910-E-16

CHARACTERISTICS

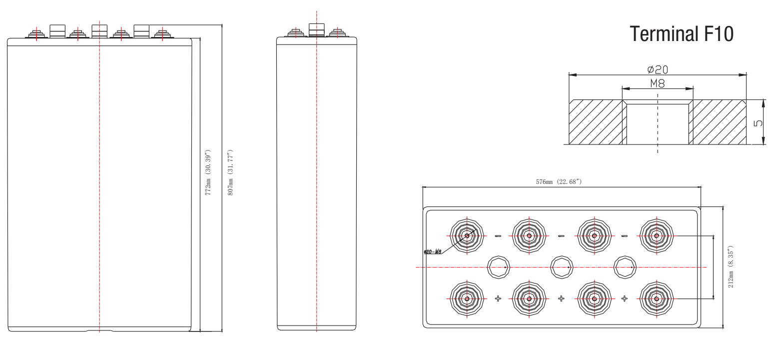
Capacity 77°F (25°C)	100 Hour Rate	3750 AH
	20 Hour Rate	3220 AH
	10 Hour Rate	3000 AH
Internal Resistance	Full charged Battery 77°F (25°C)	0.19mΩ
Capacity Affected by Temperature (20hr rate)	104°F (40°C)	105%
	77°F (25°C)	100%
	32°F (0°C)	89%
	5°F (-15°C)	79%
Self-Discharge	Less than 2% per month at 77°F (25°C)	
Max Discharge 77°F (25°C)	12000A (5s)	
Terminal — Standard	Thread insert & Bolt (F10-M8)	
Float Charging Voltage Range	2.25 to 2.3 VDC/unit Average at 25°C	
Max Charge Current	600 Amps	

CYCLE LIFE

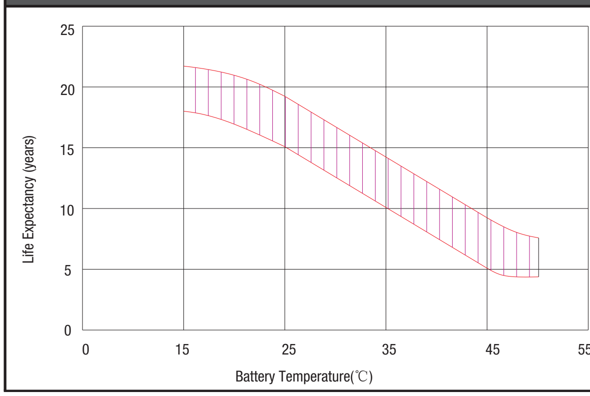


SIZE & DETAILED ILLUSTRATION

Dimension: 576mm(22.68") L ×212mm(8.35") W × 807mm(31.77") H



TEMP EFFECTS ON LIFE AT FLOAT CHARGE



Appendix H3

Schneider Electric Xantrex™ XW MPPT 80 600 Solar Charge Controller

The XW MPPT 80 600 is an innovative solar charge controller that offers an industry-first set of features: high PV input voltage (up to 600 Vdc), Maximum Power Point Tracking (MPPT), and 80 A charge current. 600 Vdc PV input voltage delivers lower installation costs through fewer PV strings, longer home runs, smaller wiring and conduit, and virtual elimination of PV combiner boxes and circuit breakers. MPPT technology helps harvest the most energy available from the PV array, regardless of environmental conditions. 80 A battery charge current allows for connection of arrays rated at up to 4800 W (48 V battery bank).

Features

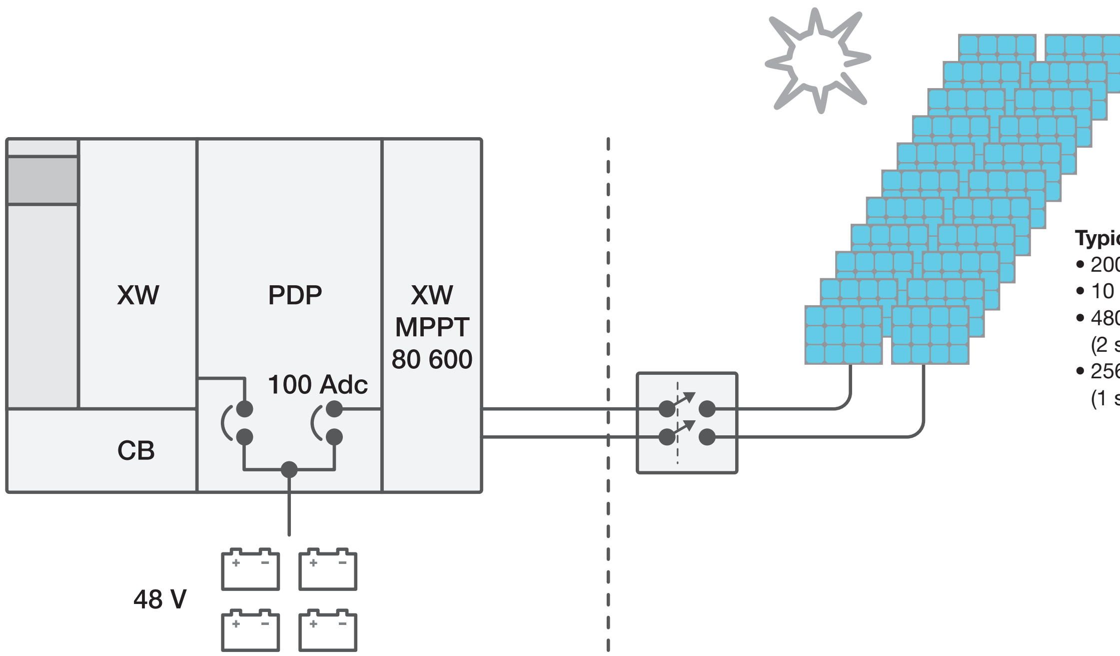
- Up to 600 Vdc input
  - Full Power Range: 230 to 550 Vdc
  - Operating Range: 195 to 550 Vdc
  - MPPT Range: 195 to 510 Vdc
  - PV Array Start Voltage: 230 Vdc
- 80 A Output; 48 V or 24 V Battery (nominal)
- Full Power (4,800 W; 2,560 W) up to 45 C (113 F)
- Fast Sweep MPPT Algorithm
- Two- or Three-stage Battery Charger, Plus EQ
- Battery Type Settings: FLA, AGM, Gel, Custom
- Battery Temperature Compensation
- High Efficiency: 96% nom @ 48 V; 94% nom @ 24 V
- Low Tare Loss (0.5 W; Xanbus Power Supply Off)
- Built-in GFP and Indicator
- Input Over-voltage and Over-current Protection
- Output Over-current and Back-feed Protection
- Over-temperature Protection
- PV Cell Compatibility: Mono, Poly, String, Thin-Film
- Selectable PV Array Grounding: (+), (-), or ungrounded
- Positive or Negative System Ground
- Xanbus Compatible with AGS, Gateway, SCP, and XW
- AUX Output (dry contact, form "C")
- PDP Mounting Compatible (30" x 8.5" x 8.5")
- Variable Speed Cooling Fans

For more information about this product email re.pvsales@schneider-electric.com

Schneider Electric

Appendix H3

Typical system configuration



Typical PV array:
- 200 W - 240 W modules
- 10 - 20 modules per string
- 4800 W max. for 48 V systems (2 strings)
- 2560 W max. for 24 V systems (1 string)

Xantrex™ XW MPPT 80 600

Device short name	XW MPPT 80 600
Electrical specifications	
Nominal battery voltage	24 and 48 V (Default is 48 V)
Max. PV array voltage (operating)	195 to 550 V
Max. PV array open circuit voltage	600 V
Max. PV array input current	35 A
Max. and min. wire size in conduit	#6 AWG to #14 AWG (13.5 to 2.5 mm^2)
Charger regulation method:	Three-stage (bulk, absorption, float) Two-stage (bulk, absorption)
General specifications	
Power consumption, night time	< 1 W
Enclosure material	Indoor, ventilated, aluminum sheet metal chassis with 22.22 mm and 27.76 mm (7/8 in and 1 in) knockouts and aluminum heat sink
Product weight	13.5 kg (29.8 lb)
Shipping weight	17.4 kg (38.3 lb)
Product dimensions (H x W x D)	76 × 22 × 22 cm (30 × 8.625 × 8.625 in)
Shipping dimensions (H x W x D)	87 × 33 × 27 cm (34.3 × 13 × 10.6 in)
Device mounting	Vertical wall mount
Ambient air temperature for operation	-20°C to 65°C (-4°F to 149°F), power derating above 45°C
Storage temperature range	-40°C to 85°C (-40°F to 185°F)
Operating altitude	Sea level to 2000 m (6562 ft)
Warranty	Five-year standard
Part number	865-1032
Regulatory approvals	
Certified to UL1741: 2nd Ed and to CSA 107.1-01; CE	

Specifications are subject to change without notice.

Make the most of your energy

Schneider Electric

Appendix H4

NEW Conext XW+ inverter/charger

One solution for global power needs

Conext™ XW+ is an adaptable single-phase and three-phase inverter/charger system with grid-tie functionality and dual AC power inputs. Available solar charge controllers, monitoring, and automated generator control modules enable further adaptability. From a single Conext XW+ unit to clusters up to 102 kW, the Conext XW+ is a scalable system that allows for the integration of solar capacity as required. Adaptable and scalable, the Schneider Electric™ Conext XW+ system is the one solution for grid-interactive and off-grid, residential and commercial, solar and backup power applications.

Why choose Conext XW+?

True bankability
- Warranty from a trusted partner with 178 years of experience
- World leader in industrial power drives, UPS and electrical distribution
- Strong service infrastructure worldwide to support your global needs

Higher return on investment
- Excellent load starting with high 30-minute and 5-second power
- Performs in hot environments up to 70°C
- Intelligent functionality enables solar prioritization, load shifting, peak shaving, and assists small generators with heavy loads
- Backup power with grid-tie functionality converts external DC power to AC power for export to the utility grid

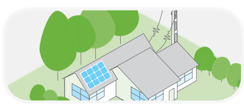
Designed for reliability
- Extensive quality and reliability testing
- Highly Accelerated Life Testing (HALT)
- Globally proven and recognized field performance

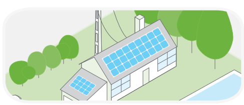
Flexible
- Single or three phase systems from 7.0 kW to 102 kW
- Supports DC coupled and AC coupled off-grid and grid-tie architectures
- Supports charging of Lithium Ion battery packs

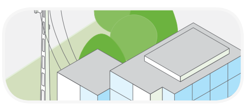
Easy to service
- Field serviceable with replacement boards and spare parts
- Monitor, troubleshoot or upgrade firmware with Conext ComBox

Easy to install
- System configures quickly into compact wall-mounted system
- Integrates both grid and generator power with dual AC inputs
- Balance of system components integrates battery bank, solar charge controllers and generators
- Commission the entire system with PC software tool and Conext ComBox

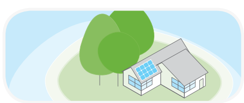
Product applications


Residential grid-tie solar with backup power


Self-consumption


Backup power


Community electrification


off-grid solar

solar.schneider-electric.com

Schneider Electric

Appendix H4

NEW Conext XW+ series (230 V)

Device short name	XW+ 7048 E	XW+ 8548 E
Inverter AC output		
Output power (continuous) at 25°C	5500 W	6800 W
Overload 30 min / 60 sec at 25°C	7000 W / 9500 W	8500 W / 12000 W
Output power (continuous) at 40°C	4500 W	6000 W
Maximum output current 60 seconds (rms)	40 A	53 A
Output frequency (selectable)	50 / 60 Hz	50 / 60 Hz
Output voltage	230 Vac	230 Vac
Total harmonic distortion (THD) at rated power	< 5%	< 5%
Idle consumption search mode	< 7 W	< 7 W
Input DC voltage range	40 to 64 V (48 V Nominal)	40 to 64 V (48 V Nominal)
Maximum input DC current	150 A	180 A
Charger DC output		
Maximum output charge current	110 A	140 A
Output charge voltage range	40 - 64 V (48 V Nominal)	40 - 64 V (48 V Nominal)
Charge control	Three stage, two stage, boost, custom	Three stage, two stage, boost, custom
Charge temperature compensation	Battery temperature sensor included	Battery temperature sensor included
Power factor corrected charging	0.98	0.98
Compatible battery types	Flooded (default), Gel, AGM, LiON, custom*	Flooded (default), Gel, AGM, LiON, custom*
Battery bank range (scaled to PV array size)	440 to 10000 Ah	440 to 10000 Ah
AC input		
AC 1 (grid) input current (selectable limit)	3 - 60 A (56 A default)	3 - 60 A (56 A default)
AC 2 (generator) input current (selectable limit)	3 - 60 A (56 A default)	3 - 60 A (56 A default)
Automatic transfer relay rating / typical transfer time	60 A / 8 ms	60 A / 8 ms
AC input voltage nominal	230 V +/- 3%	230 V +/- 3%
AC input frequency range (bypass/charge mode)	45–55 Hz (default) 40–68 Hz (allowable)	45–55 Hz (default) 40–68 Hz (allowable)
AC grid-tie output		
Grid sell on AC1 (max)	4.5 kVA	6.0 kVA
Grid sell current range on AC1 (selectable range)	0 to 20 A	0 to 27 A
Grid sell voltage range on AC1	205 to 262 Vrms (auto adjust entering sell mode)	205 to 262 Vrms (auto adjust entering sell mode)
Grid sell frequency range on AC1	48 to 51 Hz (auto adjust entering sell mode)	48 to 51 Hz (auto adjust entering sell mode)
Grid sell power factor range (lead/lag)	0.5	0.5
Efficiency		
Peak	95.8%	95.8%
General specifications		
Part number	865-7048-61	865-8548-61
Product / shipping weight	53.5 kg (118.0 lb) / 75.0 kg (165.0 lb)	55.2 kg (121.7 lb) / 76.7 kg (169.0 lb)
Product dimensions (H x W x D)	58 x 41 x 23 cm (23 x 16 x 9 in)	58 x 41 x 23 cm (23 x 16 x 9 in)
Shipping dimensions (H x W x D)	71.1 x 57.2 x 39.4 cm (28.0 x 22.5 x 15.5 in)	71.1 x 57.2 x 39.4 cm (28.0 x 22.5 x 15.5 in)
IP degree of protection	IP20	
Operating air temperature range	-25°C to 70°C (-13°F to 158°F) (power derated above 25°C (77°F)	
Warranty (Depending on the country of installation)	2 or 5 years	2 or 5 years
Features		
System monitoring and network communications	Available	
Intelligent features	Grid sell, peak load shave, generator support, prioritized consumption of battery or external DC energy	
Auxiliary port	0 to 12 V, maximum 250 mA DC output, selectable triggers	
Off-grid AC coupling	Frequency control	
Multi-unit operation	Single phase: up to four units in parallel, three phase: up to 12 units in multi-cluster configuration with external AC contractor	
Regulatory approval		
CE marked according to the following EU directives and standards:		
EMC directive	EN61000-6-1, EN61000-6-3, EN61000-3-2	
Low voltage directive	EN50178	
Safety	IEC 62109-1, IEC 62109-2	
RCM marked and compliant	AS 4777.2, AS 4777.3	

Specifications are subject to change without notice.

Conext XW+ works with the following Schneider Electric products


XW+ Power Distribution Panel
(without AC Breakers)
Product no. 865-1014-01


Conext System Control Panel
Product no. 865-1050-01


Conext Automatic Generator Start
Product no. 865-1060-01


MPPT 60 150 solar charge controller
Product no. 865-1030-1


MPPT 80 600 solar charge controller
Product no. 865-1032


Conext Combox communication device
Product no. 865-1058


Conext Battery Monitor
Product no. 865-1080-01


Conext Battery Fuse Combiner Box 250
Product no. 865-1031-01

XW Configuration Tool
Product no. 865-1155

GRUPPI ELETTROGENI
GENERATING SETS

CGM 20P

SERIE 4

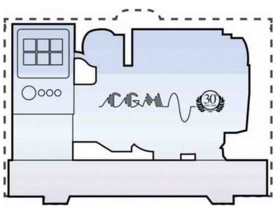
AGG. MAR 2016

MADE IN ITALY

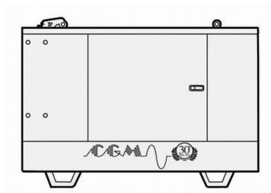
Potenza in continuo *Prime power* Puissance en continu		**Potenza in emergenza** *Stand-by power* Puissance de stand-by	
kVA	kW	kVA	kW
20	**16**	**22**	**17,6**

Condizioni ambientali *Environmental conditions* Conditions environnmentales	
Temperatura – *Temperature* – Température	40° C
Altitudine – *Height* – Altitude	1000 mslm
Umidità – *Humidity* – Humidité	60,00%

Le immagini sono puramente a titolo dimostrativo
The images are only for demonstration purposes
Cettes imàges sont utilisèes uniquement à des fins de démonstration



PESO *WEIGHT* *POIDS*	DIMENSIONI *DIMENSIONS*		
kg	L [mm]	W [mm]	H [mm]
420	1400	700	850



PESO *WEIGHT* *POIDS*	DIMENSIONI *DIMENSIONS*		
kg	L [mm]	W [mm]	H [mm]
570	1600	700	1050

C.G.M. Gruppi Elettrogeni S.r.l.
Via Decima Strada, 3 36071 Arzignano (VI) Italy www.cgmitalia.it info@cgmitalia.it
Tel. +39 0444 673712 - 674152 Fax +39 0444 675384 C.F./P.IVA 02844740247 REA 279734
Reg.Imprese VI-02844740247 - Cap.Sociale Euro 96.900,00

GRUPPI ELETTROGENI
GENERATING SETS

35° 1980-2015

DATI TECNICI *TECHNICAL DETAILS* CARACTERISTIQUES TECHNIQUES			CGM 20P
Generali – *General*	**Rumorosità (G.E. silenziato)** – *Sound level (silenced gen set)* – Niveau sonore (G.E. silencieux)	dB(A) 7mt	68
	Giri/mn – *Rpm* – Tours/min		1500
	Frequenza – *Frequeny* – Fréquence	Hz	50
	Tensione – *Voltage* – Tension	V	400 + N
	Amperaggio nominale – *Ampere rating* – Ampérage	A	29
Motore – *Engine* – Moteur	**Motore** – *Engine* – Moteur		PERKINS 404A – 22G1
	Normativa emissioni – *Engine emissions standards* – Normes d'emissions rencontrées		EU STAGE 0
	Potenza motore – *Engine power* – Puissance du moteur	Hp (kW)	24,6 (18,4)
	N. cilindri – *Nr. of cylinders* – N. cylindres		4 in linea – *in line* – en ligne
	Aspirazione – *Aspiration* – Aspiration		Aspirato - *Naturally aspirated* Aspiré
	Raffreddamento – *Cooling system* - Refroidissement		Acqua – *Water* – Eau
	Cilindrata – *Displacement* – Déplacement	cc	2216
	Alessaggio x corsa – *Bore x stroke* – Alésage x course	mm	84 x 100
	Regolatore di giri – *RPM governor* – Régulateur de tours		Meccanico – *Mechanical* Mécanique
	Precisione della regolazione – *Governor precision* – Précision régulateur	%	5%
Alimentazione – *Alimentation*	**Tipo di carburante** – *Fuel type* – Type de carburant		Diesel
	Consumo – *Consumption* – Consommation **@ 25%**	L/h	-
	Consumo – *Consumption* – Consommation **@ 50%**	L/h	2,9
	Consumo – *Consumption* – Consommation **@ 75%**	L/h	4
	Consumo – *Consumption* – Consommation **@ 100%**	L/h	5,3
	Capacità del serbatoio – *Tank capacity* – Capacité du reservoir	L	50
	Autonomia – *Autonomy* – Autonomie **@75%**	h	12,5
Alternatore – *Alternator*	**Alternatore** – *Alternator* – Alternateur		LINZ ELECTRIC
	N. di poli – *Number of poles* – Nombre de pôles		4
	Tipo – *Type* – Type		Con spazzole – *With brushes* Avec balais
	Regolazione della tensione – *Voltage regulation* – Régulation de la tension		Compound
	Precisione della tensione – *Voltage precision* – Précision de la tension	%	4%
	Diametro scarico – *Diameter exhaust* – Diamètre échappement	mm	48
	Tensione sistema elettrico – *Voltage* – Tension	V	12

Tutti i dati presenti sono contenuti nelle schede tecniche originali del motore e dell'alternatore. Essi sono indicativi e possono essere modificati in qualsiasi momento e senza preavviso.
All data can be found out in the original technical datasheet of the engine and the alternator. Values shown are nominal values, they can change in every moment and without warning.
Toutes les données sont transcrites dans les fiches techniques du moteur et de l'alternateur. Les valeurs sont nominales et ils peuvent changer à tout moment et sans avertissement

QUADRO ELETTRICO MANUALE
ELECTRICAL MANUAL PANEL
TABLEAU MANUEL DE COMMANDE

Centralina BE24 con multimetro (voltmetro, amperometro, frequenzimetro, contaore e voltmetro batteria) *BE24 control module with multimeter (voltmeter, ammeter, frequencymeter, hour counter and battery voltmeter)* Unité BE24 avec multimètre (voltmètre, amperemètre, fréquencemètre, compteur d'heures et batterie voltmètre)
Cassa in metallo IP44 – *IP44 metal box* – Boite en métal IP44
Interruttore magnetotermico Magnetothermal switch Interrupteur magnetotermal
Prese: Trifase 5P 32A + Monofase 3P 16A *Sockets: 5P Three-phases 32A + 3P Single-phase 16A* Prises: 5P Triphasé 32A + 3P Monophasé 16A
Fusibili di protezione - *Protection fuses* – Fusibles de protection
Pulsante d'emergenza – *Emergency button* – Bouton d'urgence
Galleggiante meccanico per controllo livello visivo *Mechanical floater for visual level control* Flotteur méchanique pour contrôle de niveau visuel
Allarmi pressione olio e temperatura acqua *Oil pressure and water temperature alarms* Alarmes de pression d'huile et de température de l'eau

QUADRO ELETTRICO AUTOMATICO
AUTOMATIC MAINS FAILURE PANEL
TABLEAU AUTOMATIQUE DE COMMANDE

Centralina RGK600 con multimetro (voltmetro, amperometro frequenzimetro, contaore e voltmetro batteria). Caricabatteria, funzione test periodico e riferimenti di rete. *RGK600 control module with multimeter (voltmeter, ammeter, frequencymeter, hour counter and battery voltmeter). Battery charger, periodical test function and mains measurements.* Unité RGK600 avec multimètre (voltmètre, amperemètre, fréquencemètre, compteur d'heures et batterie voltmètre). Chargeur de batterie, fonction de test périodique et mesures du réseau.
Cassa in metallo IP44 – *IP44 metal box* – Boite en métal IP44
Interruttore magnetotermico Magnetothermal switch Interrupteur magnetotermal
Morsettiera di potenza – *Power terminal* – Borne d'alimentation
Pulsante d'emergenza – *Emergency button* – Bouton d'urgence
Fusibili di protezione - *Protection fuses* – Fusibles de protection
Galleggiante meccanico per controllo livello visivo *Mechanical floater for visual level control* Flotteur méchanique pour contrôle de niveau visuel
Allarmi pressione olio e temperatura acqua *Oil pressure and water temperature alarms* Alarmes de pression d'huile et de température de l'eau

GRUPPI ELETTROGENI
GENERATING SETS

CABINA SUPERSILENZIATA DA ESTERNO
SUPERSILENT WEATHER PROOF CANOPY
CAPOTAGE INSONORISEE PAR L'EXTERNE

In acciaio, verniciata a polveri epossidiche RAL5015, per garantire un ottimale resistenza alla corrosione.
Materiale fonoassorbente resistente al fuoco ad alto abbattimento acustico.
Ottima accessibilità per manutenzioni ordinarie/straordinarie tramite robusti portelloni di accesso chiudibili con chiave.
Marmitta silenziatrice residenziale interna alla cofanatura, grado di abbattimento 35dB(A)
4 ganci di sollevamento.
Aspirazione aria dal basso lato opposto alla marmitta, espulsione aria lato marmitta sopra e sotto.

Steel structure, painted with epoxy dust RAL5015, with high resistence anti-corrosion.
Acoustic material fire-resistant with high noise reduction.
Optimal accessibility for ordinary/extraordinary maintenance through strong lockable doors.
Muffler residential type inside the canopy with 35db reduction.
4 lifting hooks.
Air intake from the opposite side of the muffler,
Exhaust air from the muffler side above and below.

Acier, peinture par poudre RAL5015, pour assurer une optimale résistance à la corrosion.
Matériel acoustique résistant au feu, avec atténuation acoustique élevée.
Facilité d'accès pour l'entretien ordinaire et extraordinaire grâce à portes d'acces verrouillables par clé.
Silencieux d'échappement résidentiel, qui coupe 35dB.
4 crochets de levage.
Aspiration air par le bas au côté opposé d'échappement, expulsion air côté échappement haut et au-dessous.

GRUPPI ELETTROGENI
GENERATING SETS

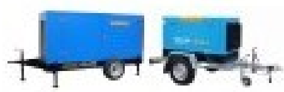
OPTIONALS

Quadro di commutazione automatica (ATS) da 32A
32A automatic transfer switch (ATS)
Inverseur (ATS) de 32A

Alternatore con regolatore elettronico di tensione (AVR)
Alternator with automatic voltage regulator (AVR)
Alternateur avec regulateur électronique de tension (AVR)

Preriscaldo
Engine preheating system
Prechaffauge moteur

Kit travaso carburante
Automatic fuel transfer kit
Kit de transfer carburant



Carrelli di traino lento o veloce
Slow or fast towing trailer
Chariot lent ou routier

FURTHER OPTIONALS

TANKS

Serbatoio maggiorato – *Bigger fuel tank* – Réservoir de plus capacité
Cisterne da esterno – *External fuel tank* – Réservoir externe
Cisterne da interro – *Underground fuel tank* – Réservoir souterrain
Valvola limitatrice di carico serbatoio – *Load limiting valve* – Soupape de limitation de charge

ELECTRIC PANEL

Interruttore differenziale – *Differential switch* – Interrupteur différentiel
Prese aggiuntive – *Further sockets* – Prises supplémentaires
Quadro di parallelo – *Parallel electric panel* – Tableau electrique de parallèle
Modem GSM – *GSM modem* – Modem GSM
Avvio con telecomando – *Remote control start* – Démarrage par télécommande
Galleggiante elettronico per interfaccia in centralina – *Electronic floater for control unit interface*
Flotteur électronique pour unité de controle avec interface
Misurazioni pressione olio e temperatura – *Oil pressure and water temperature ratings*
Données de pression du lubrifiant et de la temperature de l'eau

GENERAL

Alternatore di altra marca – *Further alternator brand* – Alternateur d'autre marque
Cabine di inferiore rumorosità – *Larger noise reduction canopy* – Capotage encore plus silencieux
Altre colorazioni – *Further colors* – Autres coleurs

MADE IN ITALY

C.G.M. Gruppi Elettrogeni s.r.l.
Via decima strada, 3
36071 Arzignano (VI) – Italy

Tel. 0039 0444 673712 – 674152
Fax. 0039 0444 675384
C.F. & P. IVA 02844720247 REA 279734
www.cgmitalia.it
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DIESEL 4000 E XL C

PORTABLE POWER

Generating Sets Range DIESEL

PRODUCT ADVANTAGES

- Entire group guaranteed 3 years
- KOHLER air-cooled industrial engine
- Large Autonomy
- Comfort of prehension thanks to the ergonomic handles
- Electric starter with batteries without maintenance

OIL SAFETY Thanks to this functionality, the engine will not start or will stop during its functioning if the oil level for gasolines or the oil pression for diesels is to low : your generating set is perfectly protected !

Range DIESEL
Both long run times and very long life for professional applications.

DIESEL 4000 E XL C

GENERAL SPECIFICATIONS

Range	DIESEL
Frequency (Hz)	50 Hz
Max power LTP (kW) *	3.40
Nominal voltage (V)	230
Number of Phase	Single phase
Fuel	Fuel
Tank (L)	16
75% cons. (l/h) *	0.90
75% Autonomy (h) *	17.80
Sound power level guaranteed LwA dB(A)	108
Acoustic pressure level @1m in dB(A)	92
Acoustic pressure level @7m in dB(A)	78

ENGINE SPECIFICATIONS

Engine brand	KOHLER DIESEL
Engine type	KD350E
Distribution	Diesel O.H.V.
Start	Electrical
Oil shutdown	Oui
Displacement (cm3)	349
Oil capacity (L)	1.20

ALTERNATOR SPECIFICATIONS

Technology	Without collar or brush
AVR Regulation	No
Indication of protection	IP 23
Insulation class	H

PLUGS AND PANEL DESCRIPTIVE

2 230V 10/16A sockets - circuit breaker

DIMENSIONS AND WEIGHT

Lenght (cm)	81
Width (cm)	55.50
Height (cm)	59
Dry Weight (kg)	84

PACKAGING

Packaging type	Box
Length (cm)	82
Width (cm)	56.50
Height (cm)	60
Weight (kg)	87
Pallet type	120/80
Number of box by pallet	6
Pallet height (cm)	193
weight of the packaged Pallet (kg)	532

SDMO Industries - 270 rue de Kerervern - CS 40047 - 29801 Brest cedex 9 – France - Tél. +33 (0)2 98 41 41 41 - www.kohlersdmo.com

DIESEL 4000 E XL C

ACCESSORIES SUPPLIED

	User and maintenance manual		Floor maintaining slot
	Ergonomic handle grip		

OPTIONS

	R01	This set includes the hour meter and the differential circuit breaker.
	R05M	The manual changeover switch is used to connect and disconnect a generating set manually to a domestic circuit when there is a power cut.
	RKB1HD	Trolley kit for the generating sets of 6kW or below
	RKDS1	Maintenance kit for KOHLER CH350E and CH440E engines (Diesel 6000 E XL C - Diesel 6500 TE XL C).
	RH1	Cover for SDMO 's generating sets, welding sets and water pumps
	RPM	Male plugs for all models made up of : 2 x 16 A/230 V, EEC17: 1 x 16A/230 V, 1 x 32A/230 V and 1 x 16A/400V
	RPQ	For earthing your generator set. Galvanised 1 m long spike, supplied with 2 m of 10 mm² cable.
	RBAC	Removable storage box

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Appendix I1

Recommended Use

Correct use of the solar power system is important to ensure continuous operation of the system. A short preliminary usage guideline is here presented, to advise the owners of the solar power system on how to use the system. A more thorough usage guideline should be developed after the system has been installed and usage data of the solar power system can be collected.

I.1.1 Recommendations

In addition to always follow monthly maintenance checklists for the solar power system and generators, the following is recommended:

- The battery status and error message log should be checked every morning and afternoon. Also check for any other faults, and verify that the status of all equipment is normal.
- If the “battery low” alarm occurs, start the 20-kVA generator. A procedure of disconnecting loads, and cutting off less vital parts of the electrical network can also be done.
- Before starting the large generator, go through a start-up procedure for the generator. A pre-made check-list is recommended.
- Stop the 20-kVA generator when the battery capacity level has reached 100 % and the “battery full” alarm occurs.
- The use of the generator should also be kept to a minimum if the fuel supply is running low.
- Use of air-condition units should only be allowed if the batteries are fully charged, or when the 20-kVA generator is running.
- The Technical Officer in charge should always be notified and give his/her approval before connecting new consumer units to the electrical network.

If the 4-kVA generator is connected to the solar power system, and in use 24 hours per day:

- Refill fuel once every morning and once in the afternoon, or whenever needed.

Appendix I2

Equipment Maintenance

The installed power system at the hospital consists of parts with different maintenance needs:

- Solar panels
- Batteries
- Charge controllers, inverters and air conditioners.
- Generators

In the following chapters, the manufactures maintenance requirements have been considered, and a more throughout description can be found in their user manuals.

I.2.1 Solar Panel Maintenance

Solar panels require little maintenance due to being an installation with no moving parts. As most suppliers of solar panels, Hanwha Solar gives a 25-year linear performance warranty for the panels used at the hospital.

However, the biggest issue with solar panels is dirt and debris that may settle on the surface after some time. It does not take much shading to lower the panels efficiency drastically. It is therefore important to inspect the panels frequently. If the panels are covered with dirt or debris, it needs to be cleaned to ensure no loss of performance.

The procedure is as followed:

- Remove all debris, and anything that might cover the panels.
- Do not scratch of dirt, but rinse it off with lukewarm water. An alcohol based glass cleaner may be used, but do not use abrasive detergents or tensides.

The system should be inspected to ensure that all components are corrosion free and that connections sit tight. All electrical components must be clean and undamaged. (Hanwha SolarOne Installation Guide, 2012)

I.2.2 Battery Maintenance

For the installation in Rotifunk, maintenance free gel batteries are used. However, to maximize the life of the battery it is important that it is being properly charged. Over or under charging will result in a shortened lifetime of the battery. It is installed charge controllers to ensure that this is done correctly, but it is important to routinely check that the charger current and voltage are at the desired levels.

A visual inspection of the batteries is also necessary:

- All cabling should be insulated and free of break or damage.
- The connectors should be clean and properly mated on the battery terminals.

Although the batteries are sealed, ventilation is still required to ensure no risk of explosive gasses. (Rolls Battery User Manual, p. 27)

Appendix I2

GEL CHARGE VOLTAGE QUICK REFERENCE

GEL BATTERIES		0°C (32°F)	10°C (50°F)	20°C (68°F)	25°C (77°F)	30°C (86°F)	40°C (104°F)
2V	CHARGE VOLTAGE	2.48 V	2.44 V	2.40 V	2.38 V	2.35 V	2.32 V
	FLOAT VOLTAGE	2.38 V	2.34 V	2.30 V	2.28 V	2.26 V	2.22 V

Figure I.1 - GEL Charge Voltages for Rolls Batteries

For the first 6-12 months of a systems life you should check the following:

Monthly
- Measure and record resting/loaded voltage.
- Record ambient temperature where the batteries are installed
- Inspect cell integrity for corrosion at terminal, connection, racks or cabinets.
- Check battery monitoring equipment to verify operation.

Quarterly
- Test ventilation.
- Check for high resistive connections.
- Check cabling for broken or frayed cables.
- Verify charge output, bulk/absorption voltage of the inverter/charge controller.
- Check cells for cracks or indication of a possible leak.
- Check ground connections.

The batteries operating temperature do also effect the lifetime of the batteries drastically. The battery enclosure in Rotifunk has an air conditioner installed to ensure good conditions, but it is important to periodically control the enclosure temperature.

I.2.3 Charge Controller, Inverter and Air Conditioner Maintenance

A visual check of the charge controller, inverter and air conditioner should be done frequently. Look for damaged parts and check the information panels for any error messages or alarms.

I.2.4 Generator Maintenance

A generator consists of mechanical parts witch needs some extra care. In addition to a general visual inspection of the generator itself, it also requires regularly checks of:

- Oil and Oil Filter – oil levels must be maintained, and oil filter should be changed once a year
- Air Filter - Change air filter once a year
- Belts - Inspect the generator belts and look for damage.
- Radiator Fluid - required level must be maintained.

Appendix J

OFF-GRID SOLAR POWER SYSTEMS IN RURAL AREAS

System Design Guideline

Preface

This guideline is a product of the bachelor thesis “Off-grid Solar Power Systems in Rural Areas” done at the Western Norway University of Applied Sciences by Trond Hjartåker and Mette Kristine Breiteig, spring 2017.

The thesis is based upon the assessment of the solar power project at Hatfield Archer Memorial Hospital in Rotifunk, Sierra Leone. The project was first carried out by Engineers Without Borders-Haugalandet, who decided on a local supplier of the solar power system, Energy for Opportunities.

The worked examples in this guideline are based on the new solar power system, and the already installed electrical system & loads at the hospital in Rotifunk. The examples are presented in their own text boxes, and can be found throughout the whole guideline.

The solar power system design used in this guideline is a direct current (DC) bus system. An alternative to this is an alternating current (AC) bus system, but this is not included in the system design. What the difference involves however, is explained in Chapter 4.

Even though every care has been done to ensure no errors or omission to occur in this guideline, the authors can take no responsibility for the use of the information given when designing any off-grid solar power system.

Front page photo: Salamat Made

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Table of Acronyms and Abbreviations

AC	Alternating Current
A	Amps
Ah	Amps-hour
C_{20}	The Battery Capacity if Discharged Over 20 Hours
DC	Direct Current
DOD	Depth of Discharge
I_{sc}	Short Circuit Current
kWh	Kilo Watt-hours
MPPT	Maximum Power Point Tracker
NOCT	Nominal Operating Cell Temperature
V	Volts
VA	Volt Amps
V_{oc}	Open Circuit Voltage
PV	Photovoltaic
PSH	Peak Sun Hour (kWh/m^2)
PWM	Pulse Width Modulation
STC	Standard Test Conditions
W	Watt
Wh	Watt-hours
˚C	Degree Celsius

1 Introduction

When designing any off-grid solar power system, a consideration of numerous factors other than the electrical load should be done (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 1):

- The budget and funds available.
- Power quality needed.
- Environmental influence.
- Aesthetics.
- Suitable back-up runtime.
- Level of noise.
- Accessibility of the installation site.
- Level of required automation.

1.1 Energy Source and Efficiency

Because of limitations of the power source and funds, alternative energy sources for cooking, heating, water heating and lighting should be considered. This could for example be a gas or wood burning stove, solar water heating or use of natural lighting. All appliances should also be chosen by their energy efficiency, to ensure the lowest possible energy consumption in the installation (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 1).

1.2 Design Standards

Different countries have different standards when designing a solar power system. It is important to have knowledge on which standard if there is any, the country or region the installation will be built in applies to (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 1).

1.3 Irradiance Data

To be able to calculate the energy that can be harvested at the different geographical sites, it is highly important to have data of the solar irradiance at that exact area. From this, the calculated area of solar panels to match your energy need will be determined (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 7). Solar irradiance data can be downloaded from different databases. In the Rotifunk Project, data was downloaded from the websites of NASA and Meteonorm.

NASA:
https://eosweb.larc.nasa.gov/sse/

Meteonorm:
http://www.meteonorm.com/

Further description on how to use the irradiance data, to determine the size of the PV array (solar panels) can be found in Chapter 5.

1.4 Simulation Program

When designing off-grid solar power systems, a simulation program can be helpful. There are several programs to choose from. In the Rotifunk Project, the PVsyst Photovoltaic Software was used. This proved to be a helpful tool when for example determining the solar fraction given with a certain combination of solar power equipment, and simplified the work. However, simulation programs are not flawless and do often have some limitations. It is therefore important to have some knowledge on how to calculate solar power systems, as will be described further in this guideline. It is possible to design a solar power system entirely from a simulation program. However, it is important to know what kind of results to expect, and from that discover any flaws in the given simulated data.

PVsyst Photovoltaic Software:

http://www.pvsyst.com/en/

2 Solar Power System Design

When designing an off-grid solar power system in rural areas there are five key issues:

- The funds available.
- The load in the installation.
- The daily energy use is not constant over the year.
- The PV array power is not constant during the day, due to irradiance hours.
- The PV array power vary from day to day, and season throughout the year.

The system design is all based on the energy available from the sun, and how this is absorbed in the solar panels, and the energy demand in the installation. The system should always be designed to meet the energy needs calculated from the month of lowest irradiance level. In Sierra Leone, this would be in July when the rainy season is at its worst.

A basic design method consists of different steps and decisions:

- Assessment of loads and energy use to determine the energy demand.
- Calculate the area of solar panels to match the energy demand.
- Estimate the required battery storage.
- Determine the required energy input from sources like the PV array, charger controller, inverter and generator.
- Determine if any further needs, or practical use of other system components.

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 2)

On the next page (Chapter 2.1) a design flow chart is presented. This highlights the main elements to consider, and can be a helpful tool when designing a new solar power system.

Appendix J

2.1 Solar Power System Design Flow Chart

Simulation Program

A simulation program can be useful when designing a solar power system. To use the program, a determination of the different technologies and models of the following must be done.

- Battery
- Solar Panel
- Charge Controller
- Inverter
- Back-up Power

Power Consumption

- pp. 4-5
- Assesment considering only the most vital loads.
- Realistic power consumption.
- AC-loads, DC-loads, or mixed?

Irradiance Data

- Download from meteo websites. p.1
- Use of simulation program. p.2

Solar Panels

- Cell technology and efficiency. pp.7,12-13,29-30
- Calculate/ use of a simulation program to find the needed PV array area. p.9
- Determine module power. pp.12-14

Battery

- Assess the need of a battey bank. p.19
- Decide the battery technology; gel or AGM is to be preferred. p.19
- Determine battery voltage. p.20
- Determine the needed days of autonomy. p.21
- Calculate/use a simulation program to find the needed capacity. pp.20-24
- Evaluate the battery enclosure. p. 19
  - Temperature
  - Ventilation

Charge Controller

- Choose control strategy; MPPT is to be preferred. p.24
- The charge controllers size should to be 25 % more than the arrays short circuit current. p.24
- Evaluate the charge contorllers input limits vs. the PV array output.pp.24-25

Inverter

- p.27
- AC-loads in the installation?
- Assess the need of single-phase or three-phase.
- Determine the output voltage. 230 V, 50 Hz or 120 V, 60 Hz.
- The inverter needs to cover:
  - The peak power consumption in the installation.
  - Have a sufficient surge capability.

Back-Up

- Determine any use/need of a generator.
  - Determine if the generator is to be connected externally or integrated in the system. p.28

Solar Power System Assesment

- Calculate/ use a simulation program to get the Solar Fraction. p.18
- Calculate /use a simulation program to get the Capasity Factor. p.17
- Calculate the Levelized Cost of Energy. p.32

3 Assessment of Loads and Power Use

With a solar power system, there will be limitations in the power it can provide. An assessment of the loads connected to the system is vital. As mentioned before, the funds available often determine the size, and therefore also the amount of power the system can provide. The connected loads must match the provided power. With off-grid solar power systems in rural areas, the kind of projects that organizations like Engineers Without Borders works with, the loads must be adapted to match the power system.

The first task when looking at the prospect of a solar power system like this, is a load assessment considering only the loads that are absolutely necessary in the installation. This determine the minimum size of the power system that can be assessed, and the minimum of funds it requires. If any additional funds are available, further developments and more loads can be considered.

When defining the energy required from the solar power system, an assessment of the connected appliances have to be done. The power usage determines the daily energy demand the solar power system must provide. The figures are reached by calculating the power needed for the different appliances, multiplied with the number of units. The total hourly power consumption of the installation is then found by the sum of every load operating within every hour.

$$P_{pr.\ load}\,(W) = \ P_{pr.appliances}\,(W) \times Number\ of\ Units \tag{1}$$

$$P_{pr.hour}\,(W) = \ \sum P_{pr.load\ operating\ within\ the\ hour}\,(W) \tag{2}$$

When the hourly consumption has been determined, the daily energy demand is found by the sum of every hourly power consumption within 24 hours (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 2-4).

$$E_{total\ pr.day}\,(Wh) = \ \sum P_{pr.hour}\,(\mathrm{W}) \tag{3}$$

With this the energy demand each day is determined, and the next step is to find the area of solar panels that can harvest enough energy to match the energy demand.

$$E_{generated} \geq E_{demand}$$

Appliances can either be powered by direct current (DC) or alternating current (AC) and an energy assessment could be done for both. AC-loads must be connected through an inverter, while DC-loads can be connected directly to the charge controller. With a split assessment on both, the inverter that meets the minimum load requirements will be determined. In the Rotifunk Project it was decided to let every load go through the inverter, being powered by 230 VAC. This simplified the work, but other alternatives like a split assessment can be considered if seen favorable with limited funds.

The total daily hourly profile can be different from month to month. This is because the power consumption may vary with the season due to different use of air conditioners, lightning etc. In the Rotifunk Project the choice was made to simplify the work by deciding the daily hourly profile to be constant over the year. This however can give a false energy demand requirement. A more thorough energy profile can be done by calculating energy demands by for example months, and then calculate with the irradiance at the exact month.

When the assessment of the power usage is done, and the given system has been calculated to match this energy demand, it is important to inform the user of the system of its limitations. A realistic energy use assessment is important. If failing to match the power usage to the power system, the worst-case scenario will be a collapse of the system (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 2).

4 Solar Power System Architecture

An important decision when designing a solar power system is to choose what kind of electrical bus architecture to use. A solar power system can be either AC-coupled, DC-coupled, or hybrid-coupled.

- **AC-coupled System -** The DC output from the solar panels is directly converted to AC for use at the consumer. If batteries are used in the system an AC/DC converter must be connected to charge the batteries (shown in Figure 4.1). Advantages with this system is that power provided from the solar panels only have to go through one conversion step, reducing electrical losses. This system is also good if there is a long distance from the solar panels to the main system. When using high voltage AC to transfer the solar power, the size of the transfer cables can be reduced. A disadvantage with this system is that stored power in the batteries must go through more than one step. First a conversion to AC from the solar panels, then a conversion back to DC to be stored in the batteries. And when power needs to be drawn from the batteries power must be converted to AC again. This increases the electrical losses (Schneider Electric, 2016, pp. 2-2).

- **DC-coupled System -** Output from the solar panels is first converted to the correct DC level, and then connected to charge the batteries. The power is then converted to AC for use at the consumer (shown in Figure 4.1). An advantage with this system is that power stored in the batteries only have to go through one conversion step from the solar panels. This reduces electrical losses for the stored power. A disadvantage is that power directly from the solar panels to the consumer must go through an extra conversion step. This increases the electrical losses for the power used during the sun hours (Schneider Electric, 2016, pp. 2-2).

- **Hybrid-coupled System –** AC-coupling and DC-coupling are used in the same system. This can be useful if solar panels are located both near and further away from the main system. It can also be useful if consumers have different needs, or the solar power system is retrofitted (Schneider Electric, 2016, pp. 2-2).

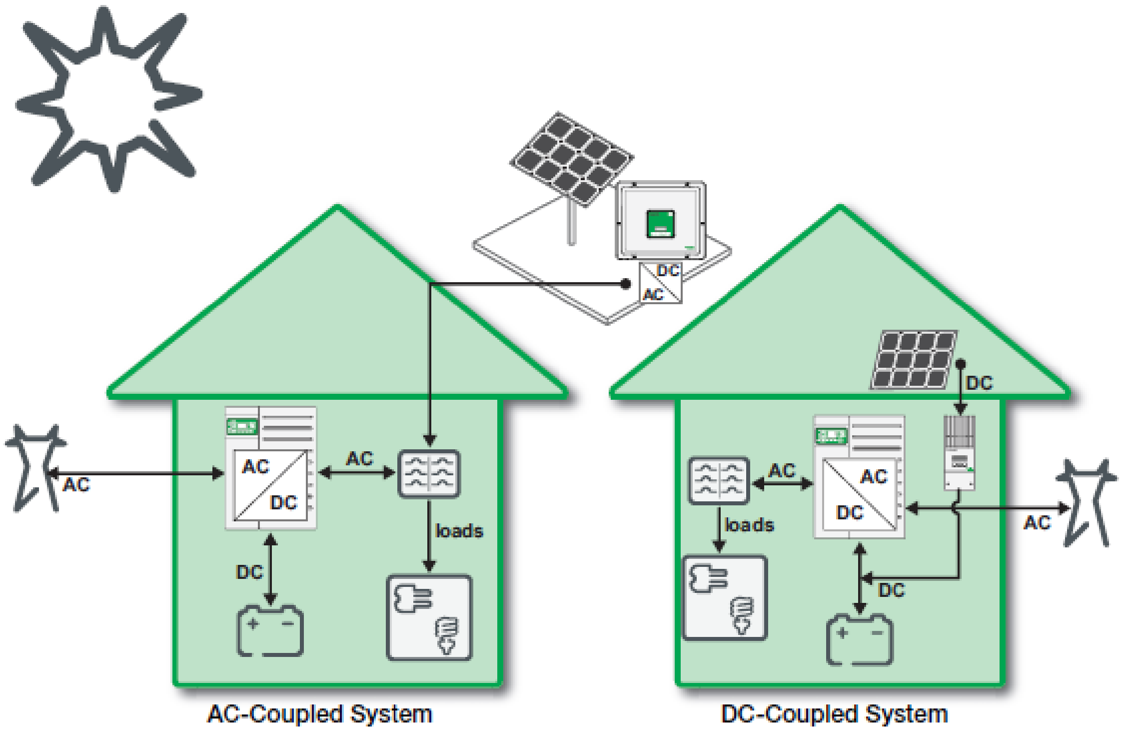

Figure 4.1 - Example of an AC-coupled and a DC-coupled Solar Power System. Source: Schneider Electric

One factor when determining the electrical architecture is the power usage profile. If most of the power is used during sun hours (Figure 4.2), an AC-coupled system can be the best choice. If most of the power is used in the evening or at night-time (Figure 4.3), a DC-coupled system would be the best choice (Schneider Electric, 2016, pp. 2-5).

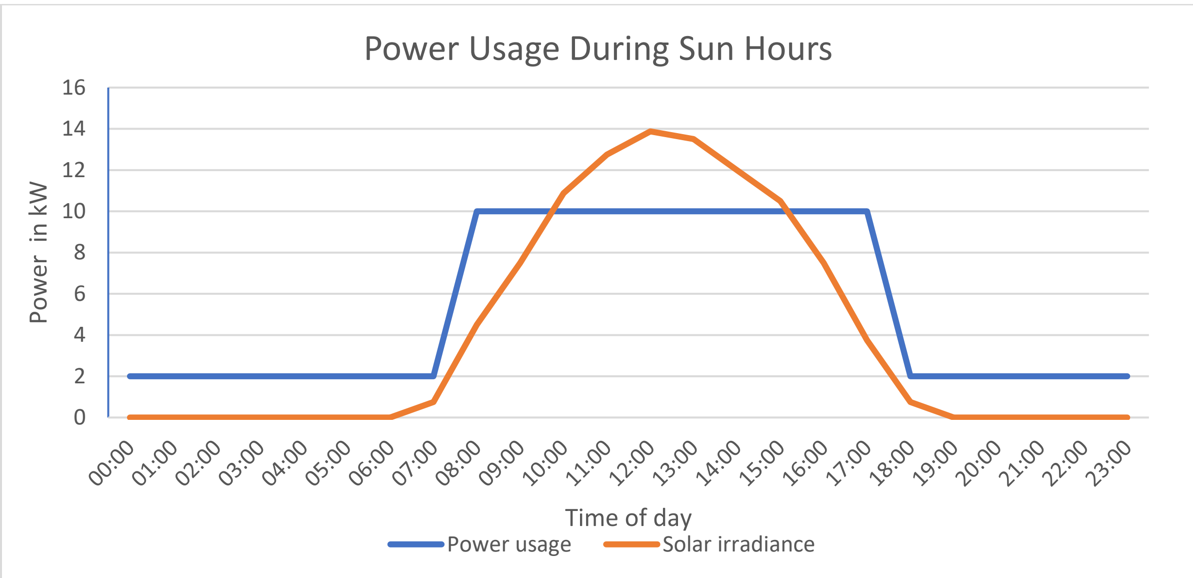

Figure 4.2 - Power Usage During Sun Hours

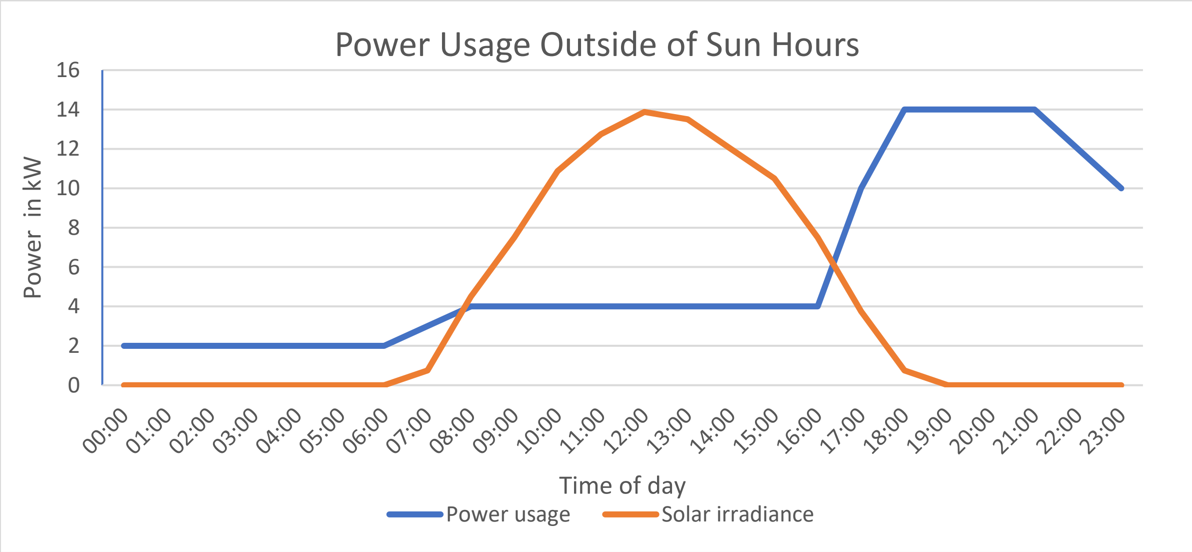

Figure 4.3 - Power Usage Outside of Sun Hours

5 Solar Panels

The size of the PV array (solar panels) depends mainly on the energy demand and the available solar irradiance, but also on what type of controller management solution that is chosen. This can either be through direct coupling, a maximum power point tracker (MPPT) or DC-DC converter. The use of an MPPT controller is more commonly used, and would be the one to prefer with its ability to maximize the provided solar energy available.

When sizing the PV array, the following must be considered:

- Variation of solar irradiance due to seasonal change.
- Variation of the daily energy use throughout the year.
- The efficiency of the batteries.
- The model manufacturer tolerance.
- Dirt and debris.
- The actual cell temperature of the array.

As mentioned in the Introduction, solar irradiance data is available from various sources. If using a simulation program, it is most likely to be connected to a meteo database. If not, solar irradiance data can be collected from websites like NASA or Meteonorm as listed. Typically, solar irradiance data is usually given in kWh/m^{2}. It can however also be listed as a daily peak sun hours (PSH). This is the number of hours that have 1 kW/m^{2} of solar irradiance. (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 7)

Figure 5.1 shows an overall illustration on the solar irradiance at various locations around the world.

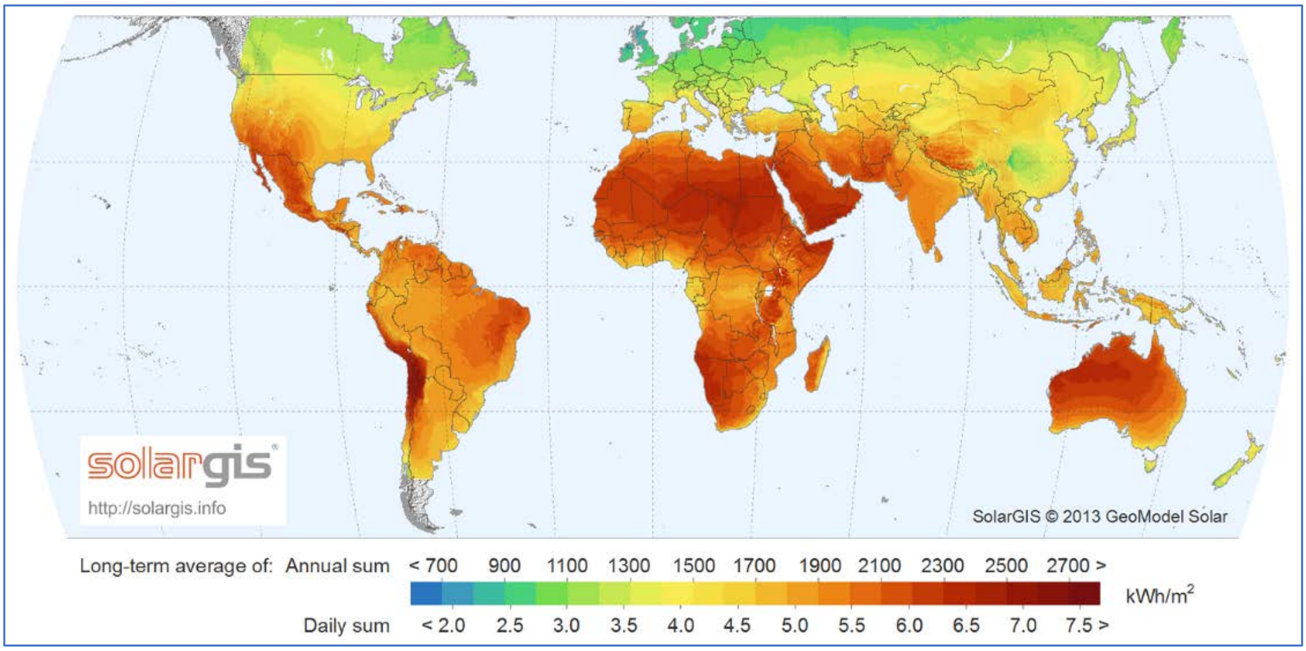

Figure 5.1 - Solar Irradiance Around the World. Source: SolarGIS

Both variations measuring the load energy need, and the solar irradiance should be considered. If the daily load is set to be constant over the year, the system should always be designed with consideration of the month of lowest irradiance at the location.

Example: Irradiance Data

At the installation site in Rotifunk, as used in the examples of this guideline, the monthly irradiance data was downloaded from Meteonorm.

Site location:

Latitude 8.19 ˚N and Longitude - 12.66 ˚W

Table 5.1 - Irradiance Data at Rotifunk

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
kWh/m^2.mth	168.0	163.2	186.2	179.0	165.1	141.2	125.2	125.9	137.7	158.6	152.1	157.7

The rainy season in Sierra Leone is from May to September. As seen from Table 5.1, July is the month with lowest irradiance. In the calculations, the irradiance data of July will be used.

5.1 PV Array Area

The size of the PV array (the area of solar panels) will determine the amount of energy that can be generated from the absorbed irradiance. With the energy demand determined, the next step is to find the size of the area of solar panels that can absorb enough energy to match the energy demand. The energy generated must be the same or greater than the energy needed.

$$E_{generated}\ (Wh) \geq E_{demand}\ (Wh)$$

Later in this chapter, it will be discussed how to calculate the number of PV modules needed with the same power consumption. When the number of units is calculated, a control-check could be made. This is to ensure that the area the number of solar panels covers, is greater than the minimum required area to generate the needed energy.

To calculate the PV array area, the following equation is used:

$$PV\ Array\ Area\ (m^2) = \frac{E_{load}}{H \times \eta_{pv} \times T_{cell-eff.} \times \eta_{out}} \tag{4}$$

E_{load}= Energy Load (Wh)
H= Solar Irradiance (kWh/m^2)
η_{pv}= The Efficiency of the Solar Panels
$T_{cell-eff.}$ = Cell Temperature Efficiency Correction Factor
η_{out}= Charge Controller Efficiency × Battery Efficiency × Inverter Efficiency × Cable Loss

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 12-15)

Example: PV Array Area

For the installation in Rotifunk, the data that is needed for the calculation was gathered from the specification sheets from the different manufacturers.

Table 5.2 - Values Used in the Calculation

Daily Energy Demand	136 538 kWh
Global Irradiance in July	125.2 kWh/m^2.mth
PV Arrays Efficiency	15.3 %
Cell Temperature Correction Factor	0.886
Charge Controller Efficiency (Nom. 48 V)	94 %
Inverters Efficiency CEC	92.5 %
Cable Loss	3 %
Battery Efficiency	90 %

Using equation four:

$$PV\ Array\ Area\ (m^2) = \frac{136\ 538\ kWh}{\left(\frac{125.2 \frac{kWh}{m^2.mth}}{31\ days}\right) \times 0.153 \times 0.886 \times 0.76} = 336\ m^2 \tag{4}$$

The needed calculated PV array area with the given energy demand is 336 m^2

5.2 Required PV Array Output

When determining the energy that is needed from the PV array, the daily energy demand in the system must be considered. The efficiency of the solar panels, batteries, charge controller and inverter must be included in the equation, in addition to a correction factor for the cell temperature. The solar irradiance data is commonly given as kWh/m^2 month. This value must therefore be divided by days before it can be used. The number of kWh/m^2 pr. day is the same value as for the PSH at the location.

Example: kWh/m^2 pr.day to PSH

The lowest irradiance level in Rotifunk is in July, having 4 kWh/m^{2}pr.day. This gives the peak sun hours to be:

$$Peak\ Sun\ Hours = 4\frac{kWh}{m^2 pr.day} = 4\ PSH$$

The PV array output is calculated by multiplying the assessed daily energy demand of the electrical system, by the correction factors of the sub system components efficiencies.

$$E_{pv\ array}(Wh) = \frac{\text{Daily Energy Demand (Wh)}}{\text{Sub. Syst. Efficiency}} \tag{4.1}$$

The sub system components efficiency involves the efficiency of the battery, charge controller, inverter and cable losses. These can be found in the components specification sheet.

The average efficiency of new batteries is estimated to be approximately 90 %. The cable loss correction factor to use in the equation is commonly estimated to be around 3 % (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 8,12).

The required PV array output is calculated by dividing the energy demand from the PV array, with the peak sun hours at the site location (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 12).

$$Peak\ PV\ Array\ Output\ (W) = \frac{E_{pv\ array}\ (\frac{Wh}{day})}{PHS} \tag{5}$$

Example: PV Array Output

In the Rotifunk Project a daily energy demand of 136 538 Wh is the calculated requirement. To find the required PV output power for this energy demand it is divided by the PSH of the location.

The sub system efficiency factor is given by the efficiency of the charge controller, batteries, inverter, and cable loss.

Table 5.3 - Sub System Efficiency Factors (η_{out})

Cable Loss	0.97
Charge Controller	0.94
Battery	0.9
Inverter	0.925

$$\eta_{out} = 0.97 \times 0.94 \times 0.9 \times 0.925 = 0.76$$

The PV array energy demand is first calculated, with consideration of the sub system efficiencies, giving:

$$Energy\ PV\ Array = \frac{136\,538\ \mathrm{Wh}}{0.76} = 179\,655\ \mathrm{Wh} \tag{4.1}$$

The Peak PV array output is then:

$$Peak\ PV\ Array\ Output = \frac{179\,655\ Wh}{4\ PSH} = 45\ kW \tag{5}$$

The required peak PV array output is 45 kW.

5.3 Oversizing the PV Array

If a generator is not connected to your system to offer extra charging to the batteries, the calculated PV array area should be oversized to cover the energy needed to charge the battery bank. This varies from the different installation location. In Australia and New Zealand, it is recommended to oversize by 30 – 100 %. In the Pacific, an oversizing of 10 % is usually enough due to the irradiance level. (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 8)

Example: Oversizing the PV Array

The site location in Rotifunk has similar irradiance levels as the Pacific. An oversizing of 10 % is therefore added to adjust the PV array output power.

This gives:

$$PV\ Array\ Output\ Power = 45\ kW \times 1.1 = 49\ kW$$

5.4 Derating of the Module Performance

The modules will experience derating due to several factors:

- **The Tolerance Given by the Manufacturer**
  - This is often given as a ± value in percentage or watts. The manufacturers derating tolerance should always be used, unless every module has been tested and the real rating is known.

- **Dirt and Debris**
  - Dirt, debris and salt can over time layer up on the array and lower its performance. This value will vary from each site, but a derating factor up to 10 % could be used.

- **Surrounding Temperature**
  - The performance of the module decreases when the temperature is higher than 25 ˚C. If the surrounding temperature is lower than 25 ˚C the modules performance increases. Because of the glass front of the module and absorption of heat, the cell temperature will be higher than the ambient temperature. This means that the output power of the module must be based upon the cells effective temperature. This can be found as followed:

$$T_{Cell-eff.}\ (℃) = T_{ave.day}\ (℃) + 25\ ˚C \tag{6}$$

Note: 25 ˚C is the manufacturer test temperature, and the given values of the solar panel is based upon this temperature.

There are three types of technology in solar power modules that are most commonly used, each have different temperature coefficients. The typical temperature coefficient is:

- Monocrystalline: -0.45 %/˚C
- Polycrystalline: -0.5 %/ ˚C
- Thin-film: From 0 %/ ˚C to -0.25 %/ ˚C

Temperature loss is then given as:

$$Temperature\ Loss\ (\%) = T_{ave.day}\ (℃) \times Temp.Coeff. \tag{7}$$

The temperature derating factor:

$$Temp.Derating\ Factor = \frac{100\ \% - Temp.\ Loss\ (\%)}{100} \tag{8}$$

To adjust the module power, the peak power is multiplied by the temperature derating factor and the dirt derating factor ($\eta_{dirt.corr}$)

$$Module\ Power\ (W) = P_{peak\ power\ module}\ (W) \times T_{derating\ factor} \times \eta_{dirt.corr} \tag{9}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 13-14)

Example: Solar Panel Derating Factors

In the Rotifunk Project, the chosen solar panel module has a peak power rating of 250 W. From the manufacturers specification sheet, different data was gathered on the chosen module.

Table 5.4 - Hanwha Solar HSC 60 Poly Can-Am 250 W Module Data

Maximum Power (P_{max})	250 W
Power Tolerance	± 3 %
Open Circuit Voltage (V_{oc})	37.9 V
Short Circuit Current (I_{sc})	8.76 A
Voltage at Max. Power (V_{mpp})	30.4 V
Current at Max. Power (I_{mmp})	8.22 A
Module Efficiency	15.3 %
Normal Operating Cell Temp. NOCT	45 ˚C ± 3˚C

The highest average ambient temperature in Rotifunk is measured in October to be 28.5 ˚C, given from the downloaded irradiance data.

The effective cell temperature will then be:

$$T_{Cell-eff.} = 28.5\,^{\circ}C + 25^{\circ}C = 53.5\,^{\circ}C \tag{6}$$

The 250 W solar panel module that are used have a polycrystalline technology, which gives a temperature derating factor of -0.40 %/ ˚C given from the manufacturers specifications.

$$Temperature\ Loss\ (\%) = 28.5\,^{\circ}C \times -0.4\ \frac{\%}{^{\circ}C} = -11.4\ \% \tag{7}$$

The temperature derating factor is 0.886

An assumption of the dirt derating factor is done, giving a value of 0.925.

With the consideration of the derating factors of the module, the adjusted output power is now:

$$Module\ Power\ (W) = 250\ W \times 0.886 \times 0.925 = 205\ W \tag{9}$$

5.5 The Number of PV Array Modules

When calculating the number of PV modules that are required to meet the energy demand of the installation, the calculated array power is divided with the adjusted module power. (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 14)

$$Number\ of\ PV\ Array\ Modules = \frac{PV\ Array\ Required\ (W)}{Module\ Power\ (W)} \tag{10}$$

Example: Number of PV Array Modules

When calculating the required numbers of solar panels for the Rotifunk Project using the results that have been calculated in Chapter 5.3 and 5.4, it gives:

$$Number\ of\ PV\ Array\ Modules = \frac{49\ kW}{205\ W} = 239\ Modules \tag{10}$$

This gives a total power of:

$$Total\ Power = \ 239\ Units \times 250\ W\ = 60\ kW$$

The number or modules are also dependent on the limitations of the chosen charge controller and its MPPT limits. This may cause the need of using several charge controller units to cover the power and current of the PV arrays. The number of panels in series and parallel will be decided from this. The charge controller in the Rotifunk Project had a limitation of two strings pr. controller, 35 A, and 195-550 V. This gave a combination with two strings of ten PV modules attached to each charge controller.

For the selected 250 W modules, the area of each module is 1.633 m^2. With 239 modules, this gives a total PV array area of:

$$Total\ PV\ Array\ Area = 239\ Modules \times 1.633\ m^2 = 390\ m^2$$

Compared with the minimum required PV array area calculated in Chapter 5.1:

$$390\ m^2 \geq 336\ m^2\ \ OK!$$

5.6 Mounting, Tilt and Solar Shadowing

The mounting and location of the solar panels are vital in terms of the absorption of irradiance from the sun. The solar panels should always face towards the sun. In general, this means that if located in northern hemisphere, the panels should face south, and in the southern hemisphere they should face north. The tilt of the panels is depending on the latitude of the location. The tilt of panels is often set to the latitude degree, but the performance can be improved by adjusting the angle for summer and winter time. A tilt degree of ± 5 degrees on the latitude is within the desired values (Landau, 2015).

$$Tilt(^{\circ}) = \ \mp 5\ Degrees\ on\ Latitude \tag{11}$$

Example: Tilt

The tilt in the Rotifunk Project was set to be approximately 12˚ south and facing south-west by 10 ˚ due to the surroundings at the site. The modules will have a fixed ground mounting. This information is given by EFO, the supplier from Freetown.

The latitude in Rotifunk is 8.19˚.

This gives:

$$3.19° \leq 12° \, south \, \leq 13.19° \quad OK! \tag{11}$$

Another crucial factor to consider for the location and mounting of the solar panels is the solar shadowing. It does not take much coverage of the solar panels surface to lower its efficiency drastically. Because of this it is important to adjust the panels to the surrounding area to make sure that no building, landscape or vegetation causes solar shadows on the panels. Because of lowered performance with surface coverage, the most important maintenance issue with solar panels is to keep the panels free of dirt and debris. In addition to ensure no outside shadowing factors to the panels location. It is also important to make sure that when mounting the panels, they do not cast shadows on each other due to the suns orbit angle. Data on the this can be found on for example. NASA`s websites and simulation programs for this is available.

The mounting location of the panels can be solved in diverse ways (Gevorkian, 2006, ss. 57-62).

- **Rooftops or Integrated on Buildings**: To use the rooftops or panels integrated on buildings could be a solution if ground space is limited, but the roofs pitch and direction must be ideal for it.

- **Fixed Ground Mounting**: as mentioned before, the area chosen for solar panels must be free of solar shadows, and be suitable for installation in terms of distance from the external solar installation equipment. Protective measures must also be considered.

- **Solar Tracking Ground Mounting**: The PV panels are moving and following the suns orbit with the help of solar trackers. This can give an increased irradiance absorption of 50 % during summertime, and 30 % during winter time.

5.7 Peak Power

If assessing an already sized PV array, it could be useful to see how the array covers any peak power consumptions in the installation.

$$E_{generated} \geq E_{peak\ power\ consumption} \tag{12}$$

Example: Peak Power

A solar power system given in a tender from EFO has a peak power of delivered energy of 20 kW, this will provide 175.2 MWh/year. The determined energy demand in the installation have a peak power consumption of 8.67 kW.

With the set solar power system, the area it covers with its solar panels is 131 m^2. The maximum power it then can provide calculated from irradiance values in July is:

$$E_{max.} = 4\frac{kWh}{m^2}\times 131m^2 \times 0.153\times 0.886\times 0.67 \approx 47.6\ kWh \tag{4}$$

The peak power consumption is found in the assessed daily profile, from 16:00 AM to 17:00 AM. The generated energy at that time can be calculated as:

$$E_{generated\ during\ SPH} = \frac{E_{generated\ pr.day}}{SPH} = \frac{47.6\frac{kWh}{m^2 pr}.day}{4} = 12\ kW \tag{5}$$

$$12kW\ \geq 8{,}67kW\ \ OK! \tag{12}$$

In the Rotifunk Project, the installed power system generates enough energy to provide for the peak power consumption with the terms of clear weather conditions. If the system did not provide enough energy, it would be necessary to look on the usage profile, the size of the peak power and the appearances of it to determine if the system should be calculated to provide for the peak power consumption. The discussion would be if the daily profile could be done differently with a different consumption pattern. If calculating a power system to provide for a power peak that only appears from time to time, with little importance, could make the total cost of the power system more than it would need to be for the intended use.

6 PV Array Performance

When the PV array is calculated, an assessment of its performance can be done. Typically, this involves the capacity factor and solar fraction.

6.1 Capacity Factor

The capacity factor is the ratio between the generated energy over a period of time, and the peak power energy over the same amount of time. This can be calculated as:

$$Capacity\ Factor\ (\%) = \frac{E_{generated}\ kWh/year}{E_{peak\ power} \times 8760\ h} \quad (13)$$

Typically, the capacity factor for solar power systems range from 10 % to 25 % with a fixed mounting and tilt. The weighted capacity factor in average for projects in Africa is approximately 22 % (IRENA - International Renewable Energy Agency , 2015, p. 92).

Example: Capacity Factor

Due to limitations of funds a 20-kW solar power system was installed in Rotifunk. Using a power consumption of 137 kWh/day, the PVsyst simulation report of the same system gave a generated energy value of 29.28 MWh/year based upon the site and installation values.

The solar capacity was calculated to be:

$$Capacity\ Factor = \frac{29.28\ MWh/year}{20\ kW \times 8760\ h} = 17\ \% \quad (13)$$

The solar power system based on the simulation results had an efficiency of 17 % due to the conditions the system is actually operating in.

Note: A simulation will never be 100 % accurate, but will give us an idea on how the system will operate. The real performance values can be expected to vary a little compared to the simulated results.

6.2 Solar Fraction

The solar fraction is how much of the energy demand in the installation (E_{load}) that is covered by the generated energy from the solar power system (E_H). This gives that the wanted value of solar fraction should be as high as possible for the installation.

$$Solar\ Fraction\ (\%) = \frac{E_H}{E_{load}} \tag{14}$$

Example: Solar Fraction

For the Rotifunk Project, the required PV array area is 336 m^2 as calculated in Chapter 5.1. Based on the sized area and the irradiance data at the site location, the calculated solar fraction in the month lowest irradiance will be:

The daily average irradiance in July at Rotifunk is 4 kWh/m^2pr.day

The daily energy demand is 136.538 kWh per day at the hospital

.

$$E_H\ (kWh) = PV\ Array\ Area\ \times H \times \eta_{PV} \times T_{cell-eff.} \times \eta_{out} \tag{4}$$

Table 6.1 - Technical Specifications of the Solar Power System

Daily Energy Demand	136.538 kWh
PV Array Efficiency	15.3 %
Cell Temperature Correction Factor	0.886
Charge Controller Efficiency (Nom. 48 V)	94 %
Inverters Efficiency CEC	92.5 %
Cable Loss	3 %
Battery Efficiency	80 %

The calculated generated energy is:

$$E_H = 4\frac{kWh}{m^2} \times 336m^2 \times 0.153 \times 0.886 \times 0.67 = 122\ kWh \tag{4}$$

Solar fraction calculated for July:

$$Solar\ Fraction\ (\%) = \frac{122\ kWh \times 100}{136.5\ kWh} = 90\ \% \tag{14}$$

7 Batteries

The batteries in a solar power system has proved to be approximately 50 % of the total cost of the system. Because of this, the assessment of the need of a battery back-up is vital to determine the funds that are needed to install the power system. After assessing the user needs and hourly consumption, it will be useful to look at the user profile to determine further system equipment. If looking at the daily profile shows that the main power usage is during daytime when solar irradiance is present, the need of batteries could be discussed. It could prove better to install a solar power system without any batteries, providing power during the day and run a small generator to provide for the needed power during the night.

The batteries in a solar power system is considered to be "the weakest link" usually having the shortest lifetime expectancy. While the rest of the components often have an expected lifetime of 20 years, the batteries often have to be changed after half of that time (Rolls Battery Engineering). The lifetime of the batteries depends on their operating conditions, especially regarding some key factors:

- **Temperature of the Batteries**
  The temperature of the batteries is highly important to consider when deciding on the location of the battery bank. A battery that is installed in a higher temperature than the manufacturers recommendation (usually 20 ˚C) will experience a critically decreased lifetime and capacity. Due to this, the battery surroundings temperature must be considered in an early stage, and separate rooms or enclosures with cooling units is recommended (Rolls Battery Engineering, 2017).

- **Maintenance**
  Different battery technologies require different maintenance. A typical maintenance issue with batteries is the refilling of distilled water. If this is done wrong, or neglected, the batteries expected lifetime falls drastically, and will cause an early collapse of the battery bank if continued. Today, gel and AGM batteries are available on the market. They are a bit more expensive, but requires no maintenance due to refilling, and are to be recommended. They do still require correct charging and some periodical maintenance, regarding visual inspections of connection points, damage, and control of the battery voltage as any battery. Gel or AGM will prove to be the better choice, unless strict maintenance procedures are guaranteed to be followed (Rolls Battery Engineering, 2017).

- **Ventilation**
  Battery storages need ventilation due to explosive gas leakage from the batteries. The risk is from hydrogen gas that are being formed when the battery is charged, and leakage of the sulfuric acid in the battery fluid. However, with the new battery technology of gel and AGM this is not seen as a problem, and ventilation is not required. Some ventilation is however still recommended (Rolls Battery Engineering, 2017).

7.1 System Voltage

The most common system voltages in a moderate size solar power system is either 12 V,24 V or 48 V. To decide which voltage to use, you need to know more about the system the batteries are providing energy to. If for example the batteries and inverter are located far from each other, a higher system voltage should be considered to cover power loss in the cables.

In general, the higher the total load, the higher the recommended system voltage.

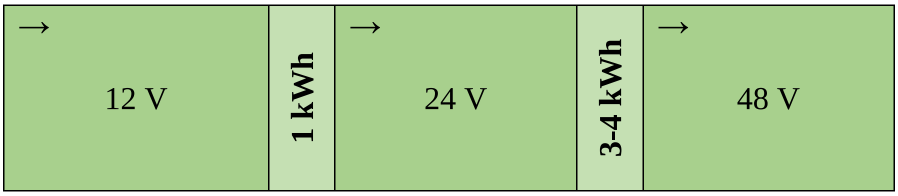

Figure 7.1 - System Voltage Based on the Daily Energy Consumption

Figure 7.1 shows a rough approach to the daily loads and what system voltage to choose. This will all depend on the actual power profile, and can in reality be a bit different.

Note: The maximum constant current drawn from the battery in general, should not be over the limit of 150 A (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 4).

7.2 Deciding on the Right Battery Size

The battery capacity is given in ampere hours (Ah). In the load assessment, the energy need is given in watt hours (Wh). When converting Wh to Ah, the total energy need, given as Wh is divided on the battery system voltage. It is important to determine the suitable capacity requirement to match the load in the installation. Oversizing may lead to sulfation issues because of incomplete charging (Rolls Battery Engineering, 2017, p. 29).

$$Battery\ Capacity\ (Ah) = \frac{Total\ Daily\ Energy\ Need\ (Wh)}{Battery\ System\ Voltage\ (V)} \tag{16}$$

Example: Battery Size

In the Rotifunk Project the daily energy requirements divided with the system efficiency is 179 655 Wh as calculated in Chapter 5.2. The battery system voltage is 48 V.

The calculated minimum capacity to match the power consumption is:

$$Battery\ Capacity(Ah) = \frac{179\ 655\ Wh}{48\ V} = 3743\ Ah \tag{16}$$

With the given daily power consumption, the batteries minimum capacity is 3743 Ah.

To determine the battery capacity, only the highest of the two requirements listed below is considered.

- The batteries ability to meet the required energy use of the system. This is often decided by the required autonomy of the system.
- The batteries ability to meet the power demand if peak power occurs.

The battery capacity is the most important parameter to determine, but when deciding on the right battery size the following critical parameters also needs attention.

Power requirements:

- The power demand each day
- The maximum depth of discharge (DOD)
- The days of required autonomy

Discharge parameters:

- The maximum current discharge limit
- The batteries need to withstand surge current

Charging parameters:

- The maximum current charging limit.

When these parameters are set, other factors can be considered to better the system's ability to meet the intended energy use by increasing the batteries capacity. These are described underneath (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 5).

1. **Days of Autonomy**

In case of low irradiance, the system may be required to provide an operating power entirely drawn from the battery bank. If a back-up generator is connected to the system it often lowers the demand of autonomy, but if more than one day of autonomy is desired the capacity and size of the battery bank must be adjusted. With off-grid system in rural areas the limitations of funds often determine the set autonomy. This must be considering in terms of the funds available, the possibility of low irradiance, and requirements of constant energy access. When discussing the energy needs in the Rotifunk Project, a set autonomy of one day was chosen due to battery costs. To maintain a constant power-level the required days of autonomy should be based upon the average number of coherent days throughout the year at the location (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 5).

$$Adj.Bat.Capasity\ (Ah) = Min.Bat.Capacity\ (Ah) \times Autonomy(days) \qquad (15.1)$$

Example: Days of Autonomy

In the Rotifunk Project only one day of autonomy was desired.

Adjusted in terms of autonomy:

$$Battery\ Capasity\ = 3743\ Ah \times 1\ day = 3743\ Ah \tag{15.1}$$

2. Maximum Depth of Discharge (DOD)

The different battery manufactures will give a recommendation on the maximum depth of discharge for their batteries in the battery specifications. If these limits are exceeded, the expected lifetime of the battery will be reduced (Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 6).

$$Adjusted\ Battery\ Capacity\ (Ah) = \frac{Battery\ Capacity\ (Ah)}{DOD\ (\%)} \tag{15.2}$$

Example: Maximum Depth of Discharge

For the batteries used in the Rotifunk Project, a DOD of 35 % was used in the calculation. The recommended DOD for an off-grid solar power system given by the manufacturer Rolls Batteries is between 20-50% (Rolls Battery Engineering, 2017, p. 29).

Adjusted in terms of DOD:

$$Battery\ capacity = \frac{3743\ Ah}{0.35} = 10\ 694\ Ah \tag{15.2}$$

3. Discharge Rate of the Battery

The battery capacity will vary with the discharge rate, and the discharge rate of the battery depends on the power consumption in the system. It is therefore important to have information about the usage time of the different appliances connected. To be able to estimate an appropriate discharge rate, a power usage profile on an average day is vital. If the system is small, this is often impractical and the battery capacity is often selected of the hourly rates of the battery. If the power usage in average is low, the autonomy can be selected based upon the 100-hr rate of the battery. If the power usage is high, it might be necessary to choose the batteries capacity and days of autonomy based upon the 10 or 20-hr rate.

In off-grid solar power systems, it is common to use the 20-hour rate when considering discharge since this is close to 1 day. The C_{20} rating refers to what load can be attached given in Amps in 20 hours before the battery voltage reaches 1.75 V per cell (Rolls Battery Engineering, 2017, p. 31).

The battery discharge rate will be given by the battery manufacturer on the specific battery model.

Example: Discharge Rate

When considering the example with DOD above, the adjusted battery capacity was 8737 Ah. In the Rotifunk Project, an autonomy of 1 day is desired. One day of autonomy is not far from the C_{20} rate of the battery. Because of this, a battery bank with a C_{20} rating close to 8737 Ah can be chosen.

$$Adjusted\ Battery\ Capasity = 10\ 694\ (@C_{20})$$

4. Derating by Battery Temperature

Temperature affects the batteries capacity and the capacity is reduced when the temperature is increased. If operating in high temperatures, a battery correction factor should be considered. This factor is set to be 1 if the surrounding temperature is 25 °C.

High temperatures affect the life expectancy of the batteries. The following graph (Figure 7.2) from the specification sheet of the S2-3220GEL Battery describes the life expectancy due to higher temperatures (Rolls Battery Engineering). In the Rotifunk Project an air conditioner was installed in the battery enclosure to ensure suitable operating temperature.

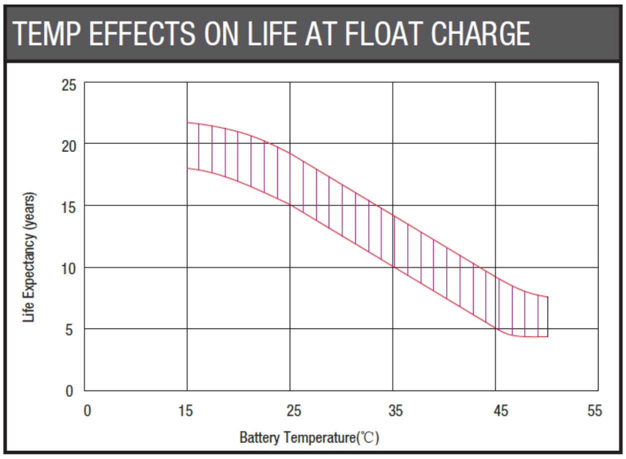

Figure 7.2 - Life Expectancy Due to High Temperatures for the S2-3220GEL Battery. Source: Rolls Battery

7.3 Battery Selection

In general, batteries or cells with a deep discharge combability is to be preferred. The batteries should be chosen to meet the requirements of voltage and capacity with a single string of battery cells in series.

If having multiple strings of batteries in parallel, an imbalance in charging may occur. If adjustments fail to be done if this happens, it will eventually lead to a premature failure of the battery bank. In addition, systems with several parallel strings requires more maintenance.

Therefore, parallel strings are not to be recommended. A fuse on each string is also required if parallel strings is necessary (Rolls Battery Engineering, 2017, p. 31).

Example: Battery Selection

With the calculated power use in the Rotifunk Project, a battery with the capacity of at least 10 694 Ah (C_{20}) should be used in the installation

8 Charge Controller

When using solar panels and batteries, a control strategy must be chosen. It can either be through direct coupling, a MPPT controller, or a DC to DC converter. The charge controllers available on the market today range from having the only task to prevent overcharge and discharge, to have additional features like:

- Pulse Width Modulation (PWM) and equalization.
- Load control
- Metering of current and Voltage.
- Logging of Ampere-hour
- Start and stop control of generators.

.
The charge controllers size should be 25 % more than the arrays short circuit current, and it should also handle the arrays open circuit voltage.

If further expansion of the PV arrays is a possibility, the charge controller should be oversized to cover the future expansion. In bigger installations, it can be required to use several charge control units due to input limitations.

The charge controllers expected input current is calculated:

$$Current_{C.C.input}(I) = 1.25\times\ Number\ of\ Strings\ (pcs)\times PV\ Array_{SC}\ (I) \tag{17}$$

$$Current_{pv\ array\ output}\ (I) \leq\ Max.Current_{C.C,pv\ array\ input}(I) \tag{18}$$

$$Voltage_{pv\ array\ output}\ (V) \leq Max.Voltage_{C.C,pv\ array\ input}(V) \tag{19}$$

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 11)

Example: Charge Controller

The solar panels from Hanwha Solar “HSC 60 Poly Can-Am” chosen for the Rotifunk Project, has an I_{sc} of 8.76 A, and a V_{oc} of 37.9 V.

$$Current_{C.C.input}(I) = 1.25 \times 2\ Strings \times 8.76\ A = 21.9\ A \tag{17}$$

$$Voltage_{pv\ array\ output}\ (V) = 37.9\ V \times 10 = 379\ V$$

The chosen charge controller from Schneider Electric “MPPT 80 600” has:

$$Max.Current_{C.C,pv\ array\ input} = 35\ A$$

$$Max.Voltage_{C.C,pv\ array\ input} = 600\ V$$

This gives:

$$Current_{PV\ array\ input} \leq Max.Current_{C.C.array\ input}\ \ OK! \tag{18}$$

$$Voltage_{PV\ array\ output} \leq Max.Voltage_{C.C\ array\ input}\ \ OK! \tag{19}$$

The charge controller sets the limit of PV array in series and parallel. Because of input limitations, several units were used in the Rotifunk Project. The total number of panels were split into groups of 10 panels × 2 strings per charge controller.

8.1 Matching PV Array Values to MPPT Specifications

If using a MPPT charge controller, it is important that the PV arrays output values matches the MPPT operating values. It must also never be greater than the MPPT maximum voltage. When the cell temperature changes, it affects the output voltage and the output power of the module. In the specification sheet from the manufacturer a voltage temperature coefficient will be specified, generally given as V/˚C or given as a percentage value.
For the V_{oc} of the PV array not to reach the MPPT maximum voltage, a calculation using the minimum day time temperature at the arrays location must be done.

The ambient temperature given in the downloaded site data, will be similar to the temperature the PV array will operate in before the sun has had time to heat up the panel. Because of this the recommended temperature to use in the calculation of maximum V_{oc} is the average minimum day temperature. The calculation of the maximum open circuit voltage is done in a similar way.

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, pp. 14-15)

Example: PV Array and MPPT Specification

With the PV panels used in the Rotifunk Project the voltage coefficient is given as -0.34 %/˚C

The minimum temperature is 23 ˚C

Open circuit voltage = 37.9 V

$$Varition\ of\ Voltage = -2\ ℃ \times -0.34\ \frac{\%}{℃} = \ 0.68\ \%$$

$$Max. V_{oc} = 37.9\ V + (37.9\ V \times 0.068) = 40.5\ V$$

The MPPT 80 600 Charge Controller used has a PV array operating voltage from 195 V to 550 V.

Max. input is 550 V:

$$Max. Number\ of\ Mudules = \frac{510\ V}{40.5\ V} = 12\ Units$$

Min. input is 195 V:

$$Min. Number\ of\ Mudules = \frac{195\ V}{40.5\ V} = 5\ Units$$

This means the MPPT can take from 5 to 12 modules per string.

9 Inverter

How to decide on an inverter for the installation depends on varied factors like cost, requirements of surge capability, and power quality needs. If an inverter/charger module is used, this can have an impact on the number of components necessary. Inverters comes with three different output wave forms. From square form to modified square wave and sine wave. Square waves are not commonly used due to their simplicity and limitation. If the installation only consists of DC loads with no plan of future expansion, there is no need for an inverter in the system.

Inverters with a modified sinewave output are usually cheaper than the sine wave inverter, and usually comes with a surge and continuous power capability. However, because of the "non-perfect" sinewave output, appliances like televisions, fans and audio equipment might suffer and a sine wave inverter is to be recommended. Often, the sine wave inverters provide a better-quality sinewave than the power grid.

The inverter should be able to cover the following two requirements:

- Be capable to supply power to all AC-loads in the installation
- Have a sufficient surge capability if having loads in the installation that may cause surge when turned on.

If it is impossible to find an inverter that meets these requirements for the system, a more thorough load and prioritization assessment must be done.

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 10)

Example: Inverter

In the Rotifunk Project, three inverters are used in a split-phase configuration to provide three-phase ,400/230V, 50 Hz to the installation. These are all connected through a bus cable, making them able to share to load.

Each of the three XW+8548E inverters has a continuous output power of 6000 W at 40 ˚C. The peak power in the installation was calculated to be 8.07 kW. Based upon the inverters ability to share the load equally, this gives the load on each inverter to be approximately 2.7 kW.

$$2.7kW \;\leq\; 6\,kW \quad OK!$$

10 Back-up Power

For a stand-alone solar power system, a back-up generator can be considered to reduce the size and cost of the system. This can be solved in two different ways.

- Use of a generator by a system switch, choosing between using the solar power system and generator. If the system is not delivering sufficient power during night/cloudy days it is possible to manually switch to generator power.
- Incorporating the back-up generator with the intention of using it as an extra battery charger when the solar power is not sufficient. This is used when the daily energy need is greater than what the daily PV array input is to the system.

The commonly used back-up is a fuel powered generator.

In terms of connecting the generator to the solar power system, an inverter/charger can be used. If this is not in your installation, a separate battery charger for the generator can be connected.

Crucial factors in terms on deciding on the use in a back-up generator is:

- Accessibility of fuel.
- Fuel storage.
- Generator loading.
- Ventilation, spillage precautions, and noise emission control.

The generator should have a load of more than 50 % of its maximum rating when in use. If the generator loading is less than 50 %, it may increase the maintenance and reduce the expected life time of the generator. A smaller generator should be considered if this continues to persist.

The charger voltage must be greater than the nominal voltage of the system. The maximum charge current of the batteries is usually around 10 % of the C_{10} rate, but will be given in the batteries specifications. The maximum charge current of the charger must never be greater then what is specified by the battery manufacturer.

(Pacific Power Association ,SEIAPI Sustainable Energy, 2012, p. 11)

11 Components and Size Vs. Cost

An important factor when designing a solar power system is the cost of every component, and the total installation cost of the power system. In recent years, the price of solar power system components has decreased significantly. This is due to the economies of scale and technological improvements. It particularly applies to solar panels, where the module cost in the last years have decreased with about 20 % for every doubling of production volume (IRENA - International Renewable Energy Agency , 2015).

Figure 11.1 shows the module cost from 1976 to 2014. The green line shows *Swanson's law* that stipulates a 20 % decrease in module cost for every doubling of production volume.

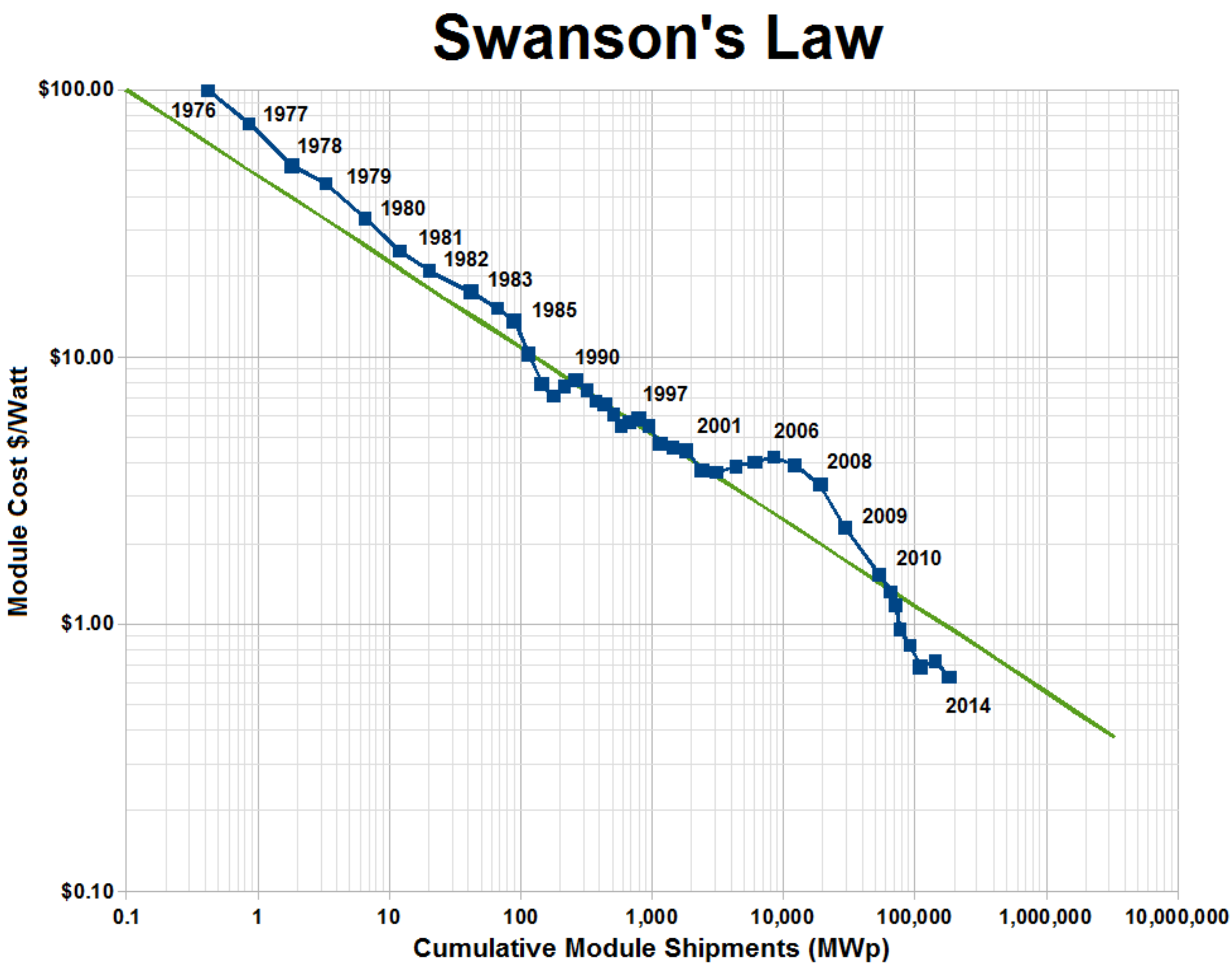

Figure 11.1 - Swanson's Law. Source: Wikipedia - delphi234

Another development in the solar power industry, is the increase in the efficiency of solar cells. Figure 11.3 on page 31, shows the efficiency of the different solar cell technologies and manufacturers from 1976 to 2016.

For the solar power system project in Rotifunk, an estimated installation cost of different system sizes was calculated. This gives an indication of what the cost of off-grid solar power systems with different sizes are in rural areas of Africa. The results of the calculations can be seen in Figure 11.2.

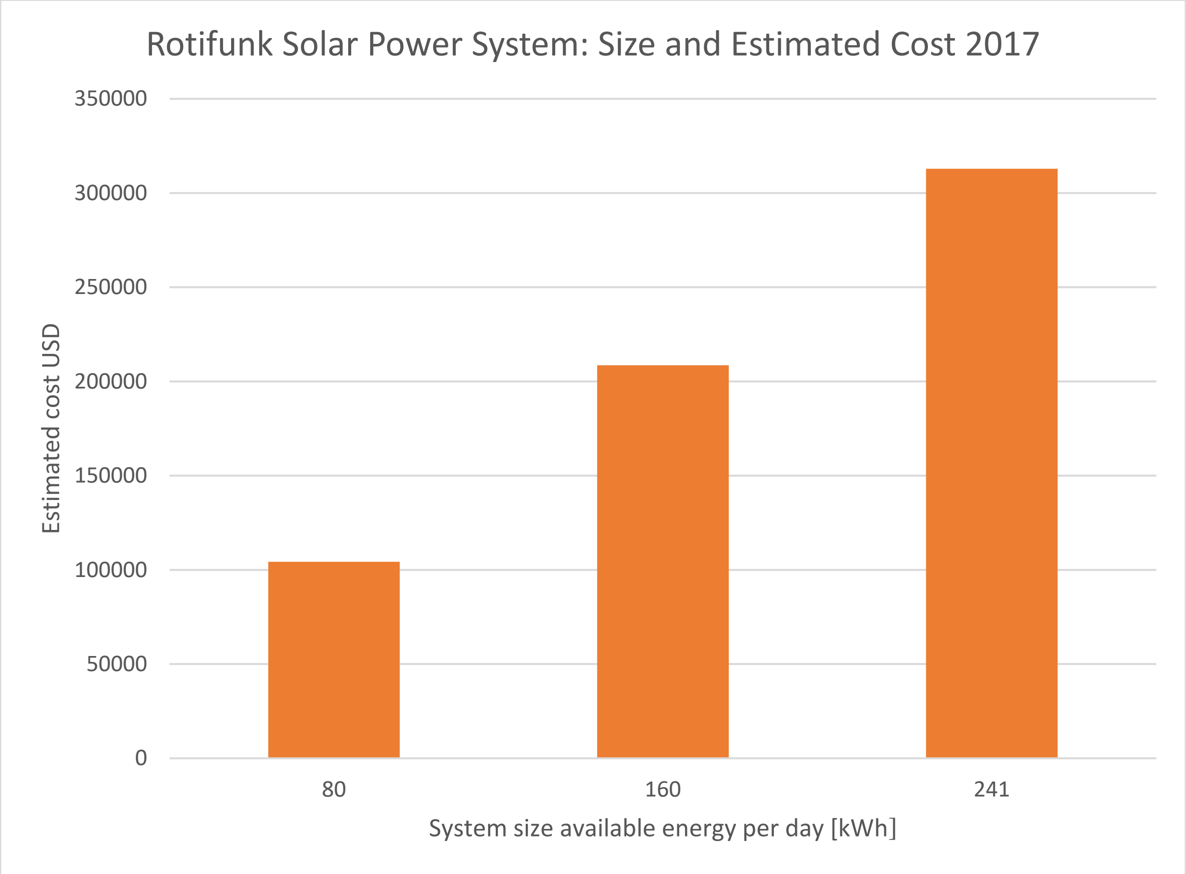

Figure 11.2 - Solar Power System Size and Estimated Cost.

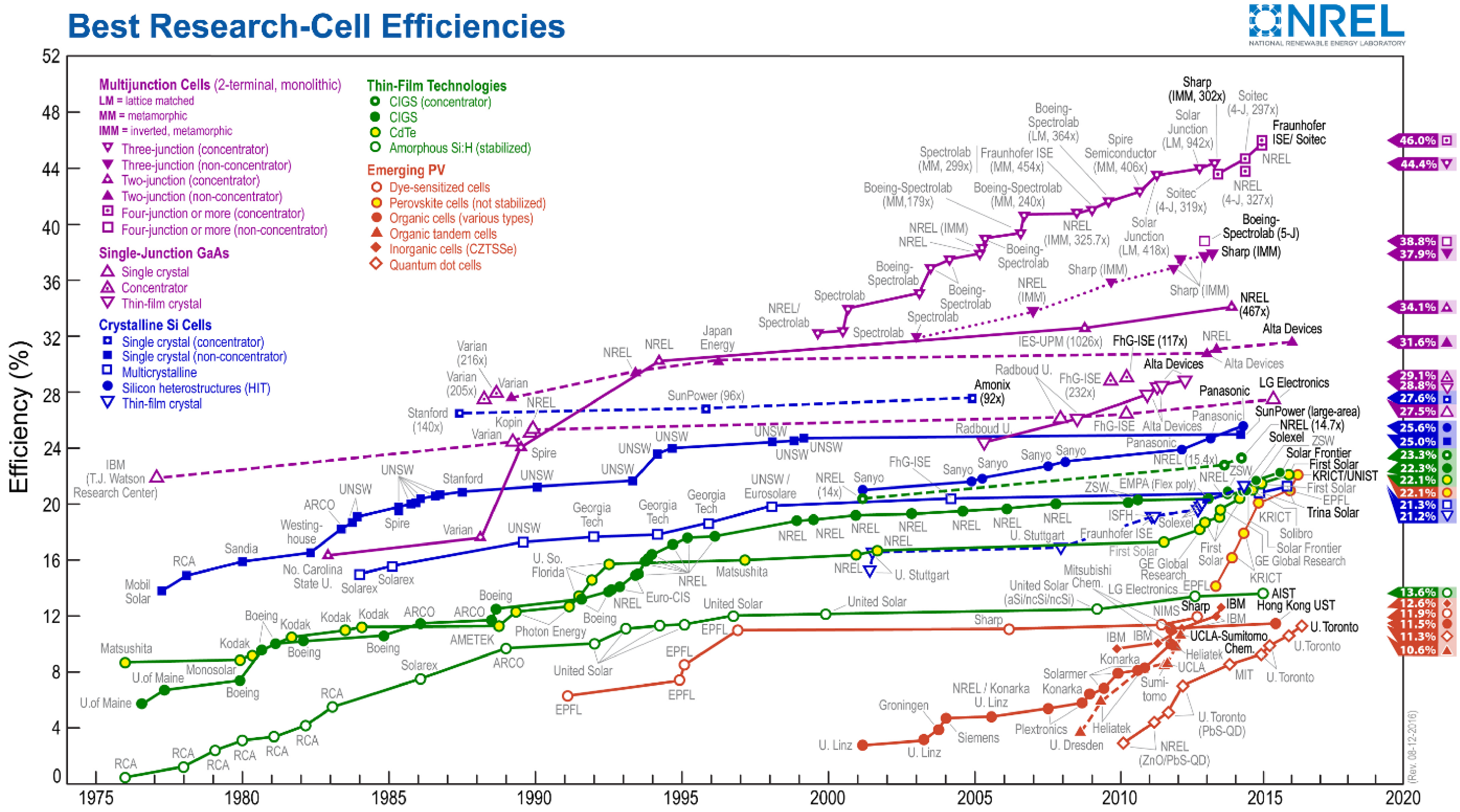

Figure 11.3 - Solar Cell Efficiencies. Source: National Renewable Energy Laboratory

12 Levelized Cost of Energy

True solar power systems have no fuel costs, but are still capital intensive when being installed. When determining the Levelized Cost of Energy (LCOE), there are three main factors to consider:

- The total cost of the installed solar power system with the electrical equipment and installation.
- The cost of maintenance and replacements of the solar power system during its lifetime.
- The energy generated throughout its lifetime, calculated with the average expected irradiance and age derating correction factor.

The key in this calculation, is the solar resource and the amount of energy that can be generated from the irradiance at the power systems location. With a grid connected system the solar power system will be economically competitive if the LCOE is the same or less than the electricity tariff (IRENA - International Renewable Energy Agency, 2017).With an off-grid solar power system it gives knowledge on how the system is performing, and if other energy sources like a generator would prove to be more cost efficient. In rural areas, this decision also leys within the level of difficulty to get hold of fuel and maintenance.

When calculating LCOE, the total cost of the power system during its lifetime, estimated to be 20-30 years is divided on the total generated energy the power system is providing within those years. The estimated lifetime of 20-30 years is an estimate for the system in general, some components may have a shorter lifetime. Batteries for example do usually have a shorter expected lifetime. This varies with the usage profile and manufacturer. Therefore, when assessing the cost of the system, the expected lifetime of every component must be considered to see if extra cost with replacement must be added.

The total cost includes the installation, maintenance and expected replacements over that period. The total energy is what the system can provide over the same period, and some derating factors due to aging of the system should be considered (Renewable Energy Advisors).

$$LCOE = \frac{Total\ Cost}{Total\ Energy\ (kWh)} \tag{20}$$

Appendix J

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