DESIGNING SOLAR POWER SYSTEM FOR OFFSHORE PLATFORM

By

FADHILA BINTI MOHAMMAD

FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

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CERTIFICATION OF APPROVAL

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Electrical & Electronics Engineering Programme
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Approved:

Ir. Perumal Nallagownden
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Fadhila Binti Mohammad

ABSTRACT

A solar power system is designed for offshore platform in order to supply power to DC loads such as emergency lighting, VHF radio, remote terminal unit, well head control panel, multiphase flow meter, fire and gas panel, marine lantern, and fog horn system. In this project, the main objective is to design, analyze and sizing the solar power system for DC loads at offshore platform. This project will be beneficial for oil and gas industries in installing their offshore platform because by using the solar power system, they can actually reduce the cost of the project in terms of supplying the DC power. A study concerning the economics of solar versus generators as a choice of power was conducted. The study considers all costs involved: modules, mounting structure, pumps, miscellaneous components, installation, operation, maintenance, yearly inspection, component replacement and salvage value. The study concludes that, the use of solar power is more reliable in terms of cost and minimum environment impact. The solar power system will be installed at a new minimum facilities wellhead platform. A common perception about solar energy is that it is expensive, but it is just the installation cost that is quite higher compared to others power supply. For an investment that will last for twenty years or more, solar power systems are very cost effective. There is almost no running cost and the replacement costs of some equipments such as batteries only occurs once in every few years. The concern is not only in solar panel, but includes battery storage system. The project is completed by designing, choosing, calculating and verifying the designed systems.

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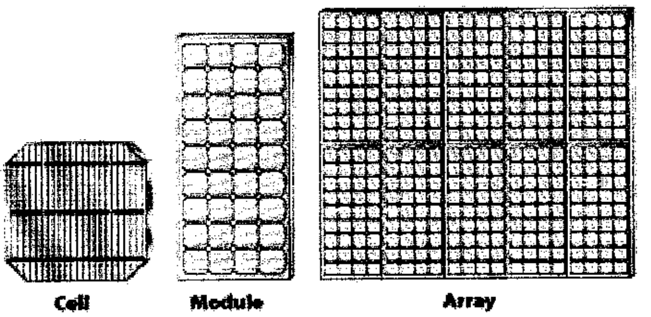
AC	-	Alternating current
Ah	-	Ampere-Hour
DC	-	Direct current
DOD	-	Depth of Discharge
LVD	-	Low Voltage Disconnect
LVDH	-	Low Voltage Disconnect Hysteresis
NiCad	-	Nickel Cadmium
PV	-	Photovoltaic
RTU	-	Remote Terminal Unit
SCADA	-	Supervisory Control and Data Acquisition
SOC	-	State of Charge
VR	-	Voltage Regulation
VRH	-	Voltage Regulation Hysteresis
VRLA	-	Valve Regulated Lead Acid

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Photovoltaic systems convert light energy directly to electrical energy. The basic photovoltaic or solar cell typically produces only a small amount of power. To produce more power, cells can be interconnected to form modules, which can in turn be connected into arrays to produce yet more power. Because of this modularity, PV systems can be designed to meet any electrical requirement, for power needs ranging from milliwatts to megawatts.



They can be used to provide power for applications as small as a wristwatch to as large as an entire community. They can be used in centralized systems, such as a generator in a power plant, or in dispersed applications, such as in rural area which is not readily accessible to utility grid lines.

A solar energy technology potentially suitable for use in offshore ocean environments includes photovoltaic technology. The hot environment, in the middle of the sea is just perfect for installation of solar power system.

The solar power system will be installed on the offshore platform situated approximately 150 km southwest of Hazira in the Gulf of Khambat, offshore Gujarat Province, India. This platform is a new minimum facilities wellhead platform (named as MTA Platform) located at the Mid Tapti Field Gas reserves. The MTA wellhead platform shall normally be unmanned. The MTA wellhead platform is designed based on minimum facilities concept. The unmanned minimum facilities wellhead platform shall be designed without the need of AC power .The solar panel will supply the DC power to several DC loads. During normal operation, which is unmanned operation, the only permanent power envisioned will be solar cells. During manned operation, the platform power supply shall be provided by Portable Diesel Engine Generator for the normal loads such as AC lighting system, receptacles, helideck lighting and charger for solar battery system. The solar power system shall be designed to meet the load requirements for MTA platform.

1.2 Problem Statement

1.2.1 Problem Identification

A study concerning the economics of solar versus generators as a choice of power was conducted. The study considers all costs involved: modules, mounting structure, pumps, miscellaneous components, installation, operation, maintenance, yearly inspection, component replacement and salvage value. The study concludes that, the use of solar power is more reliable in terms of cost and minimum environment impact. As for installation at offshore platform, the solar panel can be the best power source for some of the loads while decreasing the overall cost of offshore platform. In this project, a solar photovoltaic system will be designed to supply the DC loads requirements for offshore platform. The photovoltaic module shall be able to produce the required power to the loads.

1.2.2 Significant of the Project

The cost of installing and maintaining the offshore platform is a gigantic cost. There were some ways in reducing the overall cost while at the same time did not affect the productivity of the process. If the diesel engine generator that normally be used at offshore platform can be replaced by solar power system, then the industry should give opportunity to solar power system to prove that it also can be useful for oil and gas industry. The solar power system can be used at unmanned offshore platform that require a small amount of power supply. For continuous loads such as emergency lighting, remote terminal unit, wet gas flow meter, fire and gas detection system panel, navigational aids lantern, and fog horn system, it is best to choose solar power system rather than generator. Even though the initial cost of installing the solar power is high, but the maintenance cost is minimal and we can say its maintenance free. So, for an offshore platform, which is an investment that will last for 20 years and more, it is advisable to use the solar power system. This project is significant in supplying electricity to the DC loads for offshore platform from the solar module rather than the generator.

1.3 Objectives and Scope of Study

The objectives of designing solar power system for offshore platform are:

- To identify the most suitable type of solar power system for MTA Platform
- To design a solar power system that meets the DC power requirements of MTA Platform
- To determine the optimum type and size of solar panel required for above system
- To calculate the battery capacity for above system

In designing the solar power system for offshore platform, there are several things need to be done and taken into consideration. Before designing the solar power system, the total load requirements at the platform have to be identified and determined. The solar panel is being designed and sized in accordance with the total load requirement. Each photovoltaic solar panel array will consist of required number of individual panels. The solar panel will connected in suitable series-parallel combinations to obtain the required voltage and current rating with the aim of meeting the system requirements. The solar modules shall have suitable encapsulation and sealing arrangement to protect the cells from the environment. The arrangements of the solar panels also have to be considered to utilize the minimum space on the platform.

Designing the solar power system includes designing solar array and other electrical equipments such as battery, solar regulator, and inverter (if needed). The battery will store the power generated during the day and can be used to supply the load when bad weather condition (cloudy days) and during night. The battery banks shall be charged from the surplus power available from the solar panel array when the sunlight is available and will supply the solar electric power from the solar panel when the sunlight is inadequate under cloudy condition and during nights. But, if overcharging occurs, it will damage the battery and the system. Therefore, to prevent solar panel from overcharging the battery when it is full charged, the charge controller will be designed along with the system. The charge controller will regulate the charge of the battery, regulate the distribution voltage and monitor the battery charging current from the solar panel. It will disconnect the battery from solar panel when it is full charged.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The photoelectric effect which is the fundamental principles in photovoltaic was discovered in 1839 by Becquerel when light was incident on an electrode in an electrolyte solution. Thirty-eight years later, in 1877, Adams and Day observed the effect in solids while working with selenium. After the discovery of photoelectric effect, several pioneers such as Schottkey, Lange, and Grandahl did researches with selenium and copper oxide. In 1954, researchers at RCA and Bell Laboratories reported achieving efficiencies of about 6 percent by using devices made of p and n types of semiconductor. Further researches were made resulted in improvements in the photovoltaic devices. [1]

Photovoltaic (PV) or solar cells are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads. A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. When similar cells are connected in series, it will increase the output voltage while maintaining the output current, as shown in figure below (*refer Figure 1*). Whereas, when connected in parallel; it will increase the output current and maintaining the output voltage, as shown in figure below (*refer Figure 2*).

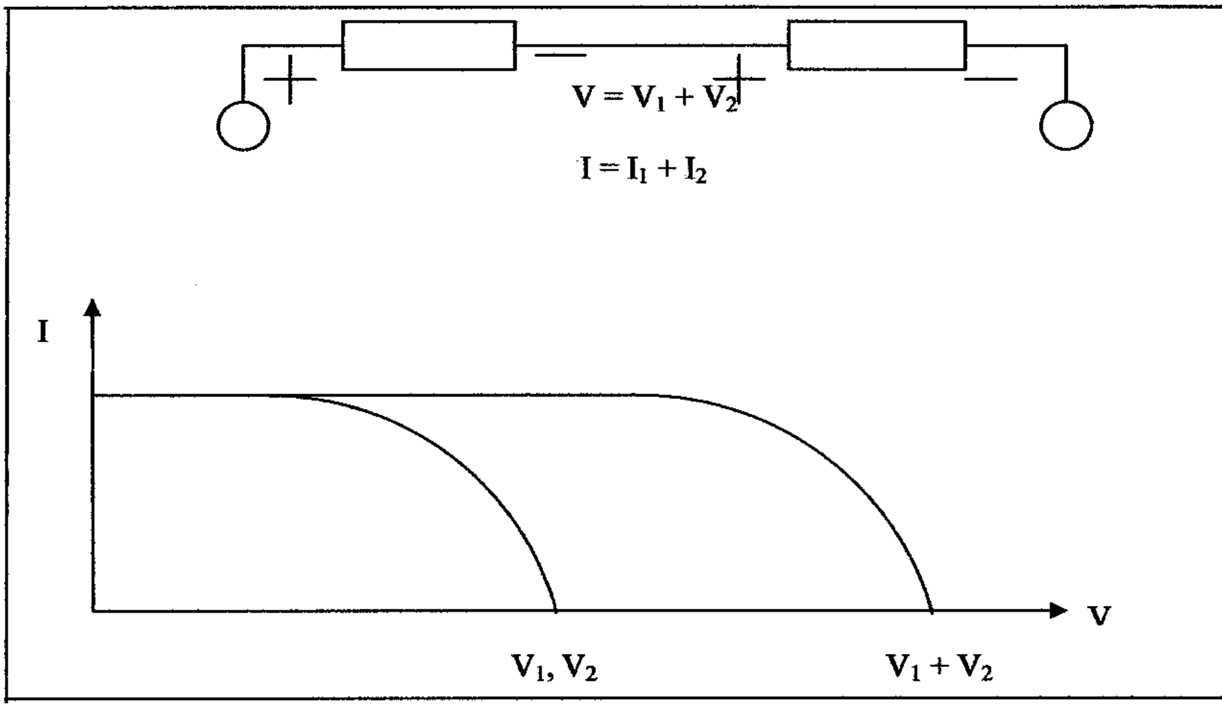


Figure 1 : Characteristics of two similar cells connected in series

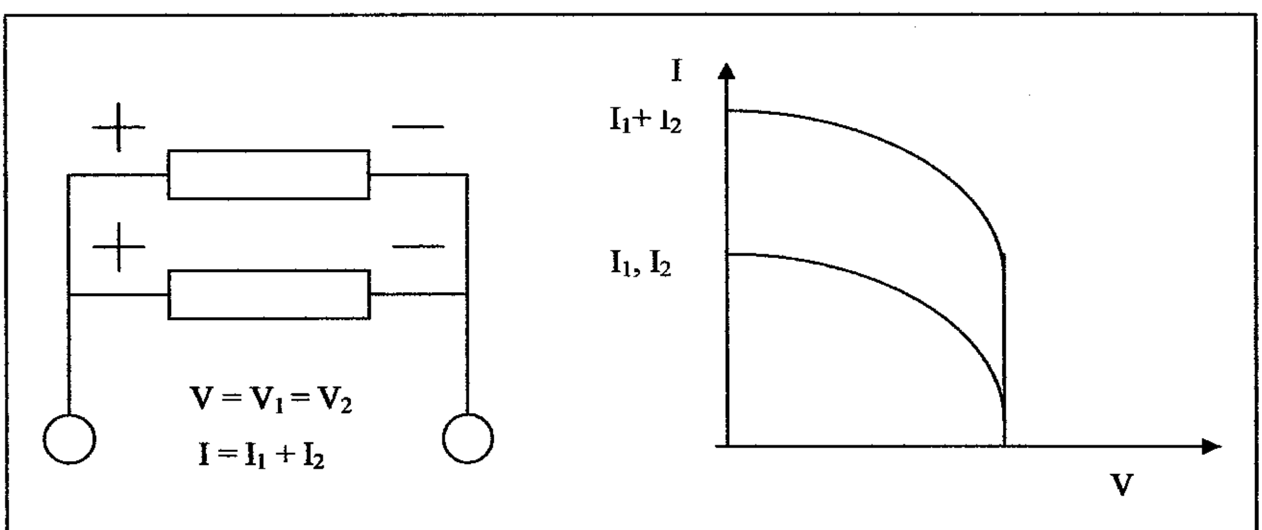


Figure 2 : Characteristics of two similar cells connected in parallel

Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

2.2 Photovoltaic System Components

Solar cells or solar panels are not the only components of a photovoltaic system. The photovoltaic system consists of a number of other parts to form a complete system. Other than solar panels as the main component, solar power system includes energy storage, power conditioning and maybe a supplementary or back-up generator to form a hybrid system.

2.2.1 Solar Panel

Solar panel converts the photoelectric effect to electricity and comes in different types and ratings. There are two main factors that determine any solar electric panel's output which are the solar irradiance, and operating temperature. For a given solar cell area, the current generated is directly proportional to solar irradiance (S). Thus, as the sun's brightness increases the output voltage and power decreases as temperature increases. The voltage of crystalline cells decreases about 0.5 percent per degree centigrade temperature increase. Therefore, arrays should be mounted in the sunniest place (no shading) and kept as cool as possible by ensuring air can move over and behind the array.

The photovoltaic cell is directly proportional to the solar intensity, and the I-V curves at different intensities are given in figure below *(refer Figure 3)* [10].

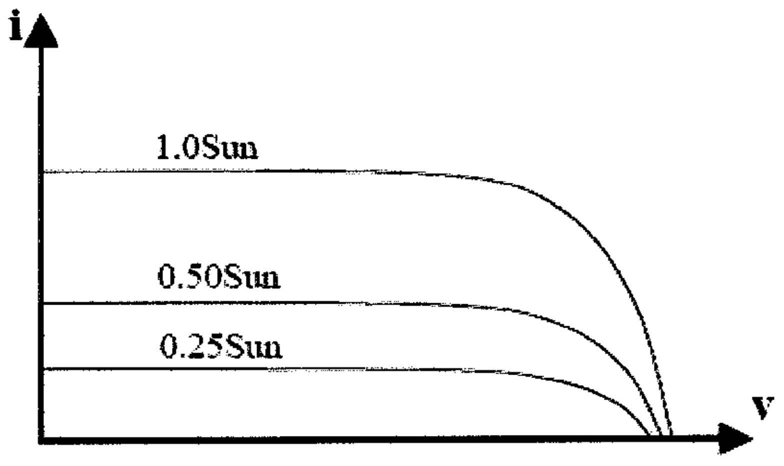


Figure 3 : I-V Characteristics of a solar cell at varied solar intensities

As temperature increases, the band gap of the intrinsic semiconductor shrinks, and the open circuit voltage (Voc) decreases following the p-n junction voltage temperature dependency. This can be seen from the curves below (*refer Figure 4)* [10].

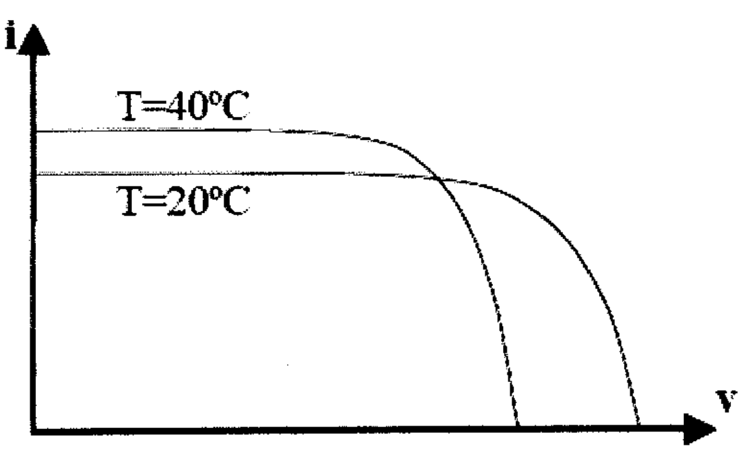


Figure 4 : Typical P-V Characteristics of a solar cell at different temperatures

The typical P-V plots at two different temperatures are shown in figure below (*refer Figure 5)* to illustrate the change in output power verses voltage due to a small rise in temperature [10].

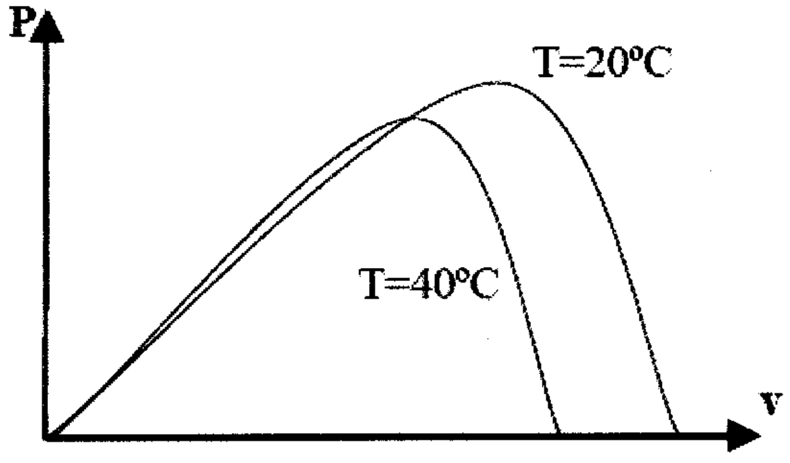


Figure 5 : Typical P-V characteristics of a PV cell at different temperatures

2.2.2 Battery System

To store electricity from solar panels, battery storage system will be needed. Solar panels charge the batteries during daylight hours and the batteries supply the power when it is needed, often at night and during cloudy weather. The battery for solar power system usually is from deep cycle battery. This type of battery is different from a conventional battery, as it is designed to be more tolerant of the kind of ongoing charging and discharging. The battery for solar power system usually has features such as high charging efficiency, good cycle life even for deep discharge, extended life expectancy, and maybe maintenance free. All of the features are important to ensure the battery can supply the power needed in case of cloudy days or during night.

The two most common types of rechargeable batteries in use are lead-acid and alkaline such as nickel cadmium. Lead acid batteries have plates made of lead, mixed with other materials, submerged in a sulphuric acid solution while nickel cadmium batteries have plates made of nickel submerged in a solution of potassium hydroxide [9]. A nickel-cadmium battery has a greater recharge cycle life than a lead-acid battery *(refer Figures 6 and 7)*. Nickel-cadmium batteries can be discharged and recharged more times than lead-acid batteries before battery cell failure occurs. Recharge cycle life for a lead-acid battery is primarily a function of how deeply it is discharged and how long it is left in that state before recharging. Typically, and depending on other conditions of use, a nickel-cadmium battery can be charged and discharged over twice as many times as a lead-acid battery. In addition, if a lead-acid battery is left for several days with a discharge of 80% or more, it may be permanently damaged and unsuitable for further use. A nickel-cadmium battery can be stored in a fully discharged condition without any detrimental effects.

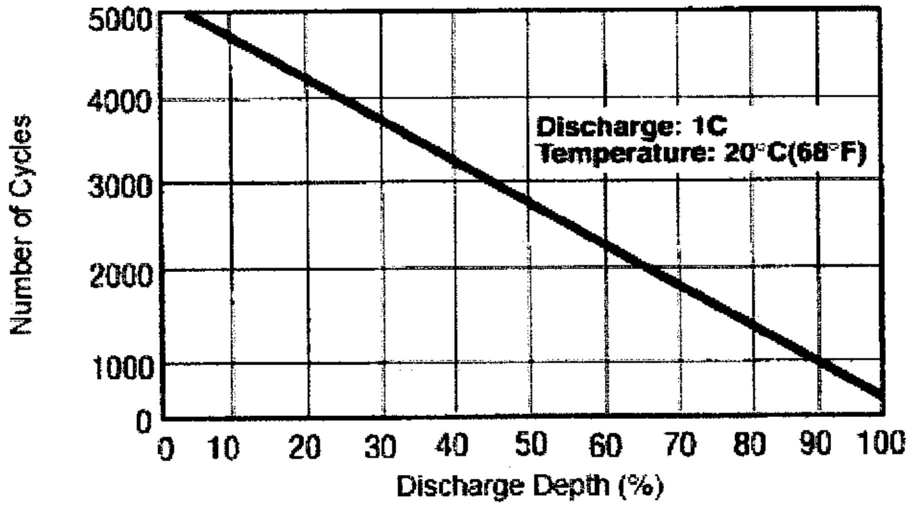


Figure 6 : Nickel Cadmium battery Cycle Life versus Depth of Discharge

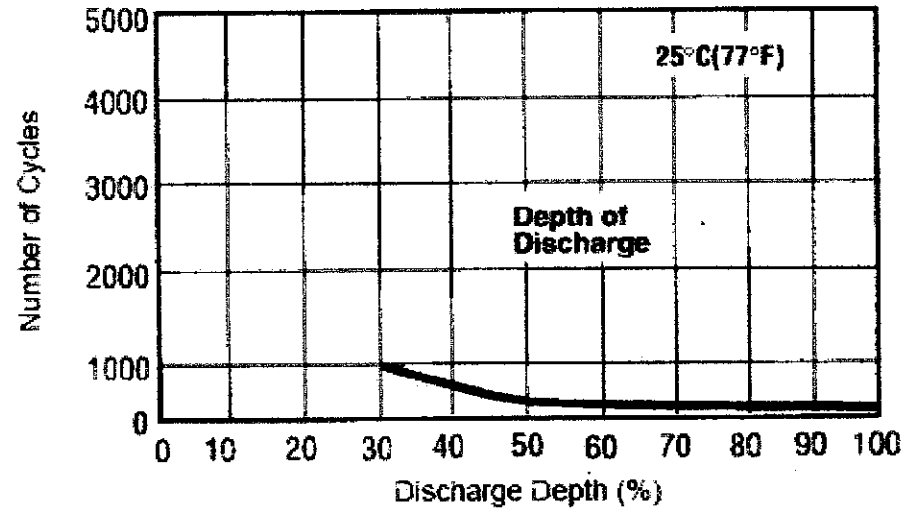


Figure 7 : Lead Acid battery Cycle Life versus Depth of Discharge

2.2.3 Charge Controller

Charge controller main function is to fully charge a battery without permitting overcharge or reverse current flow at night or during cloudy days. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge and protect from electrical overload. The charge controller is placed between the solar module and the battery. When the battery has received enough charge, the charge controller will withhold further charging. If a solar array is connected to batteries with no overcharge protection, the battery lifetime will be shortened and load availability will be decreased. There are four basic charge controller set points [11]:

- *Voltage regulation set point*: The maximum voltage that a controller allows the battery to reach. At this point a controller will either discontinue battery charging or begin to regulate the amount of current delivered to the battery.
- *Voltage regulation hysteresis*: The voltage span or difference between the VR set point and the voltage at which the full current is reapplied. The greater this voltage span, the longer the array current is interrupted from charging the battery. If the VRH is too small, then the control element will oscillate, including noise and possibly harming the switching element or any loads attached to the system.
- *Low voltage disconnect*: The voltage at which the load is disconnect from the battery to prevent over discharge. The LVD defines the actual allowable maximum depth of discharge and available capacity of the battery.
- *Low voltage disconnects hysteresis*: The voltage span or difference between the LVD set point and the voltage at which the load is reconnected to the battery. The proper LVDH selection for a given system will depend on the battery chemistry and size, and PV and load currents.

2.3 Advantages of photovoltaic system

Photovoltaic systems have several advantages over conventional power-generating technologies. Photovoltaic systems can be designed for a variety of applications and operational requirements, and can be used for either centralized or distributed power generation. Solar energy from sun can delivers free energy, and has virtually no environmental impact such as no noise emission and no pollution is created from operating Photovoltaic systems. It is modular and thus flexible in terms of size and applications. In general, PV systems that are well designed and properly installed require minimal maintenance and have long service lifetimes.

CHAPTER 3
METHODOLOGY/PROJECT WORK

The structure/procedure for the whole project is as follows:

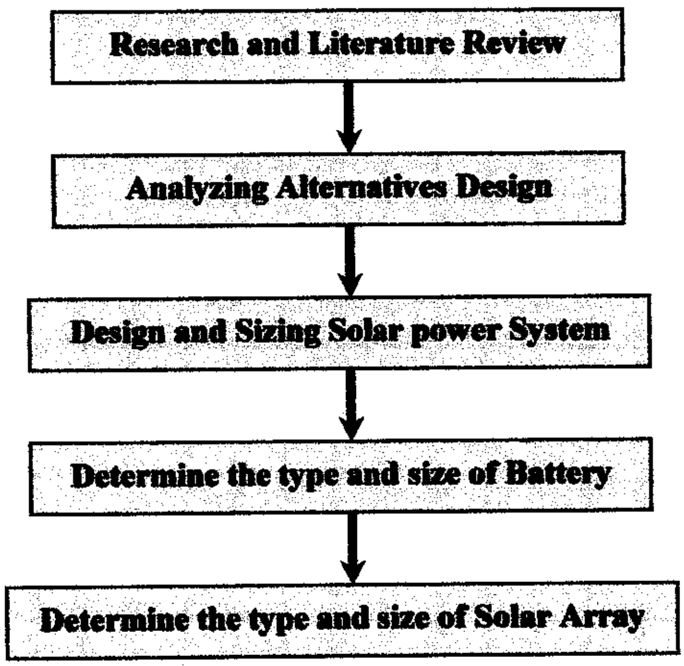


Figure 8 : Project Flowchart

In completing the project, the above flow chart was followed to ensure the smoothness of the project. First, the literature review and research on solar power system was done based on books, journal and other references to obtain a better understanding of the selected area. The research is focused on the solar panels, battery storage system, and power conditioning as the main components in solar power system. Based on the research done, the designing stage was done comprising the size and type of solar panel, and battery storage system.

3.1 Design and Sizing of Solar Power System

In designing and sizing solar power system, steps involved consists of load estimation, battery sizing, solar energy requirement, and number and size of solar panels.

3.1.1 Load Estimation

The estimation of loads and load profile are important in designing solar power system since the system will be sized to satisfy the demand of the loads. For this project, the loads use can be obtained from single line diagram (*refer appendix A*). The loads identified for MTA Platform are:

i. Emergency Lighting

In the event of an emergency situation requiring building evacuation, emergency lighting guide occupants to the nearest path of way out, helps prevent injury and plays a key role in the smooth, quick, successful passage of occupants to safety.

ii. VHF Radio

The VHF radio used to communicate between the offshore personnel and the onshore personnel or with others. The VHF radio is used when there is personnel at the platform and if some information or data need to be transmitted to the other personnel.

iii. Remote Terminal Unit

Remote terminal units (RTU) collect data automatically and connect directly to sensors, meters, loggers or process equipment. They serve as slave units to supervisory controllers or supervisory control and data acquisition (SCADA) masters. Remote terminal units are located near the monitored process and transfer data to the controller unit on command. Intrinsically safe remote terminal units are designed to operate safely in hazardous environments. Devices with weather tight enclosures are designed to prevent the ingress of moisture, dust or other environmental contaminants. If needed, redundant RTU will be used. Redundant RTUs are complete remote terminal units that contain all of the transceivers, encoders, and processors needed for proper functioning in the event that a primary RTU stops working. The RTUs are designed for process monitoring

iv. Wellhead Control Panel

Wellhead control is a convenient lever-operated accessory incorporating a 4-way valve and catcher device. Mounted on the wellhead, the control valve permits easy pump in, pump out and retrieval operations where hydraulic type pumps are installed down hole. A wellhead control is used to control the pressure within the wellhead. A wellhead is part of an oil well which terminates at the surface where petroleum or gas hydrocarbons can be withdrawn.

v. Multiphase Flow Meter

The multiphase flow meter used to measure oil, gas and water flow rates to increase flexibility in well completion option. Use of a multiphase flow meter is used to help to maximize oil output and improve reservoir management. It has also served as a check on production testing and allocation. By using a multiphase flow meter, accurate real time data of well production can be obtain and the effects of changing the operating parameters of an individual well can be reviewed. By using the data acquired, the changes in the flow of the oil, gas and water can be monitored and if anything happens, the specific solution can be used immediately.

vi. Fire and Gas Panel

A Fire and Gas System is mainly concerned with detection, annunciation and mitigation of fire and/or gas hazards. It must perform this function without itself creating further hazards. Fire and Gas Systems typically have the following basic components and sub-systems; detectors, barriers, input units, logic/control system, annunciation/displays, audible alarms, manual controls, interface to other safety systems, output units, and actuators

The total power requirements then can be obtained from the loads listed. The load usage profile can be determined by knowing the power of each loads and the duty cycle used per day. The basic equations used in estimating loads:

$$\text{Power of Appliance} \times \text{No of Units} \times \frac{\text{Efficiency}}{100} = \text{Total power (watt)}$$

$$\text{Total power (watt)} \times \text{Daily Duty Cycle (hours)} = \text{Total Power (watt-hour)}$$

$$\text{Total Power (watt-hour)} \div \text{Supply Voltage (V)} = \text{Total Power (Ampere-hour)}$$

3.1.2 Battery Sizing

The battery will be charged from the surplus power available from the solar panel array when the sunlight is available and provide electricity during the nights or for periods with low or no insolation such as cloudy days. In sizing the batteries, the autonomy times which is the number of full days that a fully charged battery can supply power to the specified load, without any charging by solar modules [2], had to be determined.

The design criteria for the designing the batteries are as follows:

- Battery configuration per system - 1 x 100%

- Nominal voltage - 24 V DC
- Ageing degradation - 10%

There are a design allowances that has to be followed during the battery sizing and in order to choose the best battery that suits the requirements. The design allowances for battery sizing are as follows:

- 10% allowance for battery ageing effects
- 20% maximum depth of discharge for daily load cycle
- 80% maximum depth of discharge during autonomy period
- 7% loss allowances for battery recharge, inefficiency and float charge
- 0.1% loss allowances for battery self-discharge

The required minimum battery capacity per battery system can be calculated from:

Daily Power Consumption (Ah) ÷ Max percentage discharge allowed (max DOD) ÷ Ageing Factor ÷ Temperature Correction Factor = Required Minimum Battery Capacity (Ah)

3.1.3 Solar Panel Sizing

The solar panel array is designed based on insolation data at specific location. The insolation data at Mumbai High, coordinates 19° 07'N, 72° 51'E is attached in appendix section (*refer Appendix B*). The sizing of solar panel is based on the worth insolation data which occur on August with 3.86 kWh/m^2/day.

In the calculations of the solar array, the following design criteria will be applied:

- Solar array per system - 1 x 100%
- Nominal voltage - 12 V

- Worst case insolation - 3.86 kWh/m²/day

The following design allowances will be applied in sizing the solar panel:

- Degradation over life span - 15%
- Alignment/Tilt errors - 2%
- Fouling - 1%
- Cell mismatch - 2%
- Losses (solar controller/cables) - 3%

The total design allowances that will be applied are 23%. This design allowance will be used in calculating the size of array.

The calculations involved are:

[Daily recharge load from full discharge] + [Daily power consumption] + [Battery recharge inefficiency loss] + [Battery self-discharge loss] = [Solar power requirements]

[Nominal system voltage] ÷ [Module peak voltage] = [No of module in series]

[Equivalent sun hour (from insolation data)] x [Module peak power current x design allowances + additional output due to temperature] = [Single module capability]

[Solar energy requirements (Ah)] ÷ [Single module capability] x [No of module in series] = [Min no of modules per array]

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Study of Power Supply Choices

The study had been done to compare the power choices at MTA platform. There were three options that has been considered which are:

- Option 1: Solar Power as primary source and back up Diesel Engine Generator
- Option 2: Micro turbine Generator as primary source and back up Diesel Engine Generator
- Option 3: Gas Engine Generator as primary source and back up Diesel Engine Generator

In option 1, the solar power will be the permanent power during unmanned operation and diesel engine generator will supply power to AC loads during manned operation. During unmanned operation, only the DC loads will be operating, hence the solar power will supply power to the DC loads.

In option 2, the micro turbine generator will provide permanent source of power to the loads while diesel engine generator will be a standby source. The micro turbine generator will operate as 1x100% scheme and the diesel engine generator also will operate as 1x100% scheme.

In option 3, gas engine generator will provide primary power source to the loads and diesel engine generator will act as standby power source. The gas engine generator will operate as 1x100% scheme and the back up diesel engine generator also will operate as 1x100% scheme.

All three options were analyzed in terms of costs, reliability, availability, environmental impact, safety, operability, maintainability, and noise emission. The comparisons of three options were summarized in a table below (*refer Table 1*).

Table 1 : Comparisons of Three options of Power Choice

No.	**Criteria**	**Option 1: Solar Power, back up Diesel Generator**	**Option 2: Micro turbine, back up Diesel Engine Gen.**	**Option 3: Gas Engine Gen., back up Diesel Engine Gen.**	**Remarks**
1	Reliability	Solar power supply is considered a very reliable source	Quite reliable, but not much information is available since it is quite new in market	Very reliable since the gas engine unit is proven a reliable machine	
2	Availability	High availability as the sun is always available	High availability. Fuel gas is always available	High availability. Fuel gas is always available	Option 1 & 2 require fuel gas treatment
3	Minimum Environmental Impact	Zero emission	Low NOx emissions	Low emission engine type can be specified	
4	Safety	Low personnel risk. Very safe	Medium personnel risk due to less frequent visit	High personnel risk due to frequent visit	
5	Operability	Very easy to operate	Easy to operate	Easy to operate	
6	Maintainability	Very low maintenance. Battery replacement every 20 years	Low maintenance. - 7500 hours between service interval - 40000 hours between overhaul	High maintenance. - 100-500 hours for service interval - 4000 hours for overhaul interval	

			The micro turbine is air-cooled, air-lubricated and has only one moving part. There are no fluids (no oil, no coolant) to change	Requires motor oil for lubricant and glycol/water for coolant	
7	Noise	Zero noise emission	70dBa at 10m	Noisy	
8	Total Cost	Medium cost ~USD753.02k	High cost ~USD818.6k	Low cost ~USD717k	

Table 1 shows that in terms of cost, Option 3 has the higher cost and may not be considered as a power choice at MTA Platform. For overall criteria, Option 1 which is solar power with diesel engine generator as back up power source has more advantages especially in terms of maintainability, operability, safety, minimum environmental impact, and noise emission. Therefore, Option 1 is being chosen as the power supply at minimum facilities platform, MTA Platform.

4.2 Solar Power System

The continuous DC power at the platform will be supplied by solar power obtained from solar panels. Due to huge size of the loads, there were 4 separate systems namely:

- System I : Electrical Emergency Lighting system
- System IIA : Instrumentation and Telecommunication Power system
- System IIB : Instrumentation and Telecommunication Power system
- System III : Marine Navaids system

Each system has their own loads and will use separate solar panels to power them. The loads for solar power system for four systems consists of emergency lighting, VHF radio, remote terminal unit and microwave radio, wellhead control panel, multiphase flow meters, fire and gas panel, navaids lanterns, foghorn and fog detector. The single line diagram shows all the loads connected to the solar panels (*refer Appendix A)*. The load listed in the single line diagram then being analyzed and total up to obtained the total load requirement for the solar power system.

4.3 Solar Panel

The main component of solar power system is of course the solar panel itself. There were different types of solar panels with each of them has different technologies. Basically, the solar electric panels are made from silicon and were divided into three main category based on how they are manufactured. The technologies used to manufacture mono-crystalline, poly-crystalline and amorphous silicon is differs from each other.

Mono-crystalline or (single crystal) technology are cut from a crystal that has grown in only one plane or (one direction). Single crystalline are more expensive to manufacture and typically have a slightly higher efficiency than poly-crystalline cells which results in smaller individual cells and a slightly smaller module.

On the other hands, poly-crystalline or (multi-crystalline) technology is cut from a crystal that grows in multiple directions. Poly-crystalline solar cells typically have a slightly lower efficiency resulting in larger individual cells and a slightly larger module.

There is a new technology in the solar cell technologies which is Amorphous or thin film technology that would offer a reduction in the cost of manufacturing solar modules. Thin film or amorphous technology has a lower efficiency rating so thus panels that are manufactured from this process tend to be substantially larger in size requiring a greater roof area for a typical installation. But it is a new technology that is not really established yet. The comparison of these three types of solar panels is being summarized in the table 2 below *(refer Table 2).*

Table 2 : Comparison of three types of solar panels

Type	**Mono-crystalline Silicon**	**Poly-crystalline Silicon**	**Amorphous Silicon**
Efficiency	15 - 18 %	13 – 15 %	5 - 8 %
Performance	Remains fairly constant during the first few months	Remains fairly constant during the first few months	Lose about 25% of their output during the first few months of use
Prices	Higher	Higher	Lower

Based on comparisons of three types of solar panels, it is clear that mono-crystalline silicon is the best choice in designing solar power system that will last for 20 years. Even though the price is higher compared to others, it will give better performance as it has the highest efficiency among others.

4.4 Battery

The other main component of the solar power system besides solar panels is the batteries. There were several types of batteries in the market that can be used in the industry. The major types of batteries available in the market nowadays are vented/flooded Lead Acid, Valve Regulated Lead Acid (VRLA), Vented/Flooded Nickel Cadmium and Semi-Sealed/Low-Maintenance Nickel Cadmium. Each of these types has it own unique advantages and disadvantages when being considered for a particular application. The comparison of these types is presented in the Table 3 below *(refer Table 3).*

Table 3 : Comparison of different battery types

Battery type	Advantages	Disadvantages
Vented/Flooded Lead Acid	• Low initial purchase cost • 10-20 year design life options is available • Less sensitive to temperature, compared to VRLA	• Require regular maintenance to replace water losses during normal operation • Special handling requirements required for hazardous liquid's • Damaged if discharged to zero volts
Valve Regulated Lead Acid (VRLA)	• Low initial purchase cost • Minimal maintenance required • 5,10 & 15 year design life options available	• Recommended operation temperature 20-25°C – battery life halved for every 10°C above 25°C • Battery state if charge can only be determined by external monitoring circuit
Vented/Flooded Nickel Cadmium	• 20 years design life • Suitable for extreme temperatures • Mechanically and electrically very robust • Can be restored to near full capacity after being discharged to zero volts	• High initial purchase cost • Require regular maintenance to replace electrolyte losses during normal operation • Special ventilation requirements required to disperse gases produced during normal operation
Semi-sealed/Low-maintenance Nickel Cadmium	• 20 years design life • Minimal maintenance required • Suitable for extreme temperatures • Can be restored to near	• High initial purchase cost • Special shipping/handling requirements due to hazardous nature of materials used • High disposal cost at end

	full capacity after being discharged to zero volts	of life

For this project, the battery type chosen was the low-maintenance nickel cadmium battery. It is due to low maintenance cost and it is suitable for extreme temperatures which happen at offshore platform.

4.5 Electrical Load List

In sizing the solar array, the first thing is to determine the power consumption demand. A list of equipments and the power wattage of the equipments is determined. All the data for the equipments used is summarized in the load list *(refer Table 4).*

Table 4 : Electrical Load List for each system

Electrical Emergency Lighting (System I)					
	Voltage	Op. Power	Averaged Loads		
	V DC	W	Hrs/day	Wh/day	Ah/day
Emergency Lighting	24	220	14	3080	128.3
Total Load per 24hr cycle		220		3080	128.3
Design Margin		at 0%		0	0
Design load per 24hr cycle		**220**		**3080**	**128.3**

Instrumentation and Telecommunications Power (System IIA)					
	Voltage	Op. Power	Averaged Loads		
	V DC	W	Hrs/day	Wh/day	Ah/day
RTU & microwave radio	24	316	24	7584	316
Wellhead control panel	24	8	24	192	8
VHF radio	24	140	0.857	120	5
Total Load per 24hr cycle		464		7896	329

Design margin		At 0%		0	0
Design load per 24hr cycle		**464**		**7896**	**329**

Instrumentation and Telecommunications Power (System IIB)					
	Voltage	Op. Power	Averaged Loads		
	V DC	W	Hrs/day	Wh/day	Ah/day
Multiphase Flow Meters	24	180	24	4320	180
Fire and Gas Panel	24	175	24	4200	175
Total Load per 24hr cycle		355		8520	355
Design margin		At 10%		852	35.5
Design load per 24hr cycle		**390.5**		**9372**	**390.5**

Marine Navaids (System III)					
	Voltage	Op. Power	Averaged Loads		
	V DC	W	Hrs/day	Wh/day	Ah/day
Navaids Lantern	24	10.6	16	169.6	7.067
Fog Horn	24	37.06	24	889.4	37.06
Fog Detector	24	5.56	24	133.4	5.56
Total Load per 24hr cycle				1192	49.69
Design margin		At 0%		0	0
Design load per 24hr cycle				**1192**	**46.69**

The data for the load list above is obtained from the single line diagram and from calculation. After the load list is obtained, the next step is to size battery for each system according to the chosen battery type which is nickel-cadmium battery.

4.6 Battery Sizing

The battery sizing was done based on Sunica.plus nickel-cadmium battery. The nickel cadmium battery was chosen based on performance over lead acid battery. It has resistant to over and under charging and complete discharge and it also can achieve up to 8000 cycles at 15% depth of discharge during its 20 years life. The catalogue for the chosen battery type is being attached in appendix section *(refer Appendix C)*. The details calculation for each system is being attached in appendix section *(refer Appendix E)*

4.6.1 Electrical System (System I)

For Electrical System (System I), the calculation is done based on 14 hours autonomy period. The summary of battery sizing for System I is as follows:

Average daily load = 128.3 Ah (from load list)

Required minimum battery capacity per battery system = 191.6 Ah

Actual selected battery capacity = 213 Ah C_5 (based on battery catalogue)

Solar energy requirements = 21.3 Ah/day

4.6.2 Instrumentation and Telecommunication System (System IIA)

For System IIA, the calculation is done based on 7 days autonomy period. The summary of battery sizing for System IIA is as follows:

Average daily load = 329 Ah (from load list)
Required minimum battery capacity per battery system = 3442 Ah
Actual selected battery capacity = 4400 Ah C_{120} (based on catalogue)
Solar energy requirements = 474.4 Ah/day

4.6.3 Instrumentation and Telecommunication System (System IIB)

For System IIB, the calculation is done based on 7 days autonomy period. The summary of battery sizing for System IIB is as follows:

Average daily load = 390.5 Ah (from load list)

Required minimum battery capacity per battery system = 4085.4 Ah

Actual selected battery capacity = 4400 Ah C_{120} (based on catalogue)

Solar energy requirements = 562.2 Ah/day

4.6.4 Navaids System (System III)

For Navaids System (System III), the calculation is based on 7 days autonomy period. The summary of battery sizing for System III is as follows:

Average daily load = 49.7 Ah (from load list)

Required minimum battery capacity per battery system = 519.8 Ah

Actual selected battery capacity = 645 Ah C_{120} (based on catalogue)

Solar energy requirements = 86.2 Ah/day

4.7 Solar Array Sizing

The solar array sizing was done based on Shell Powermax^{TM} Ultra SQ85-P solar modules. All of the calculations for solar array are based on the insolation data for Mumbai High for worst month (August). Below is the world insolation map used in sizing the solar array *(refer Figure 9).*

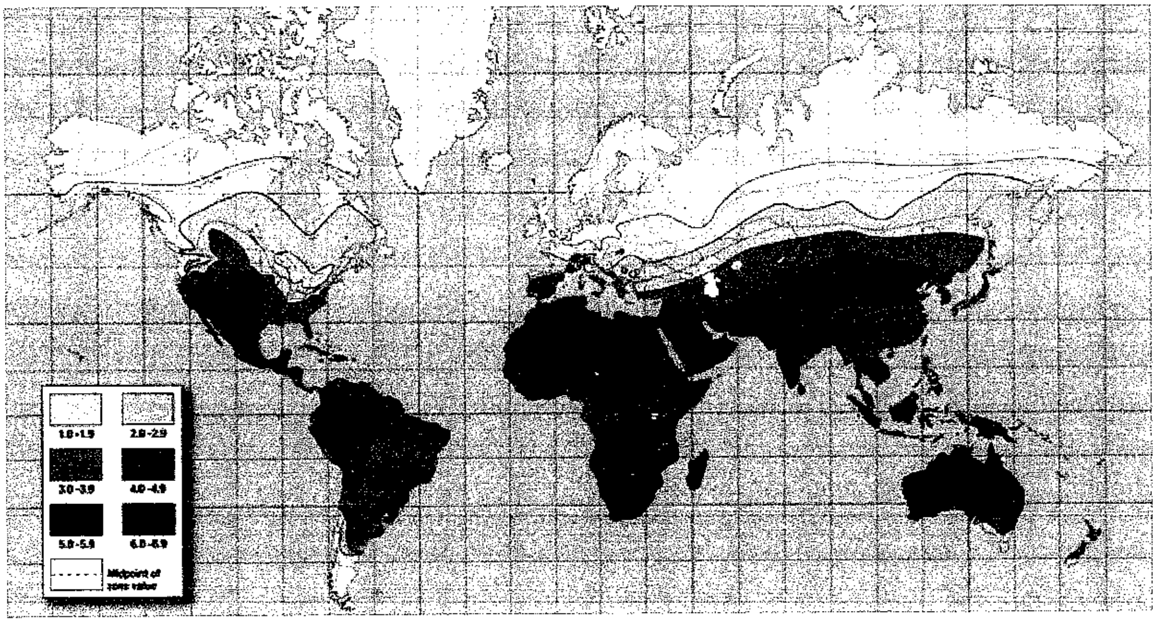


Figure 9 : World Solar Insolation Map

The Insolation data for Mumbai High is being attached in appendix section *(refer Appendix B)*. The catalogue for chosen solar modules is being attached in appendix section *(refer Appendix D)*. The details calculation of solar array sizing is being attached in appendix section *(refer Appendix E)*.

4.7.1 Electrical System (System I)

The summary of solar array sizing for System I is as follows:

Daily load energy = 21.34 Ah
No of series module connections per array = 2
Minimum no of modules per array = 2.79 modules
Selected no of modules per array = 4
Capability of array = 30.59 Ah/day

4.7.2 Instrumentation and Telecommunication System (System IIA)

The summary of solar array sizing for System IIA is as follows:

Daily load energy = 474.36 Ah
No of series module connections per array = 2
Minimum no of modules per array = 62.03 modules
Selected no of modules per array = 62
Capability of array = 474.09 Ah/day

4.7.3 Instrumentation and Telecommunication System (System IIB)

The summary of solar array sizing for System IIB is as follows:

Daily load energy = 562.21 Ah
No of series module connections per array = 2
Minimum no of modules per array = 73.52 modules
Selected no of modules per array = 74
Capability of array = 565.85 Ah/day

4.7.4 Navaids System (System III)

The summary of solar array sizing for System III is as follows:

Daily load energy = 86.25 Ah
No of series module connections per array = 2
Minimum no of modules per array = 11.28 modules
Selected no of modules per array = 12
Capability of array = 91.76 Ah/day

4.8 System Block Diagram

System block diagram shows the interconnection of components in solar power system. For each four systems, namely Electrical System (System I), Instrumentation and Telecommunication System (System IIA), Instrumentation and Telecommunication System (System IIB) and Navaids System (System III), the interconnection is the same but the number of solar panels and battery capacity is differs. The number of solar panels and battery capacity for each system is obtained from calculation earlier.

4.8.1 Electrical System (System I)

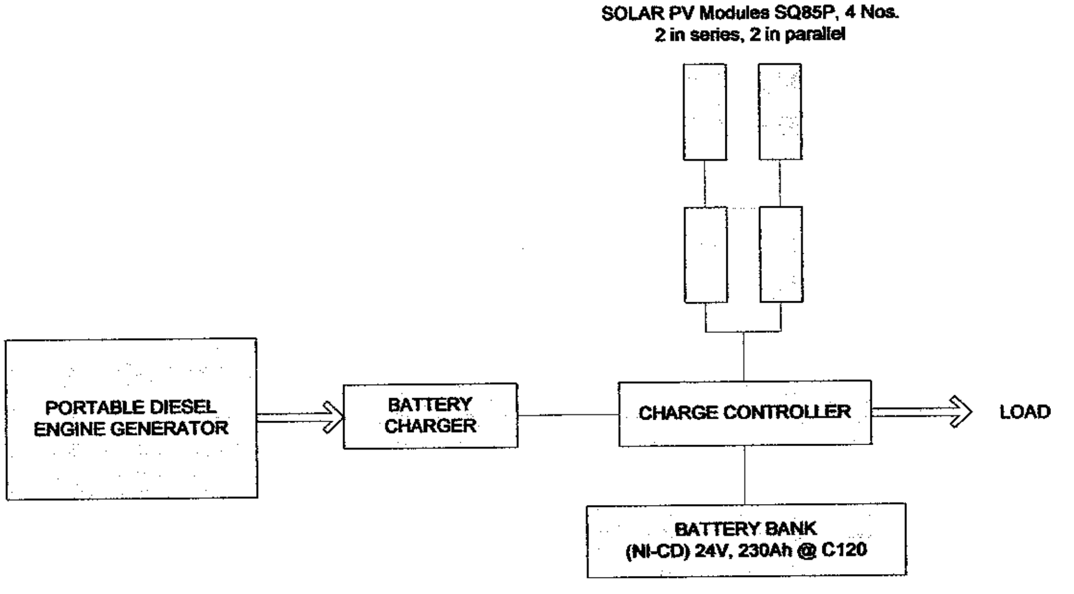


Figure 10 : Block Diagram for Electrical System (System I)

4.8.2 Instrumentation and Telecommunication System (System IIA)

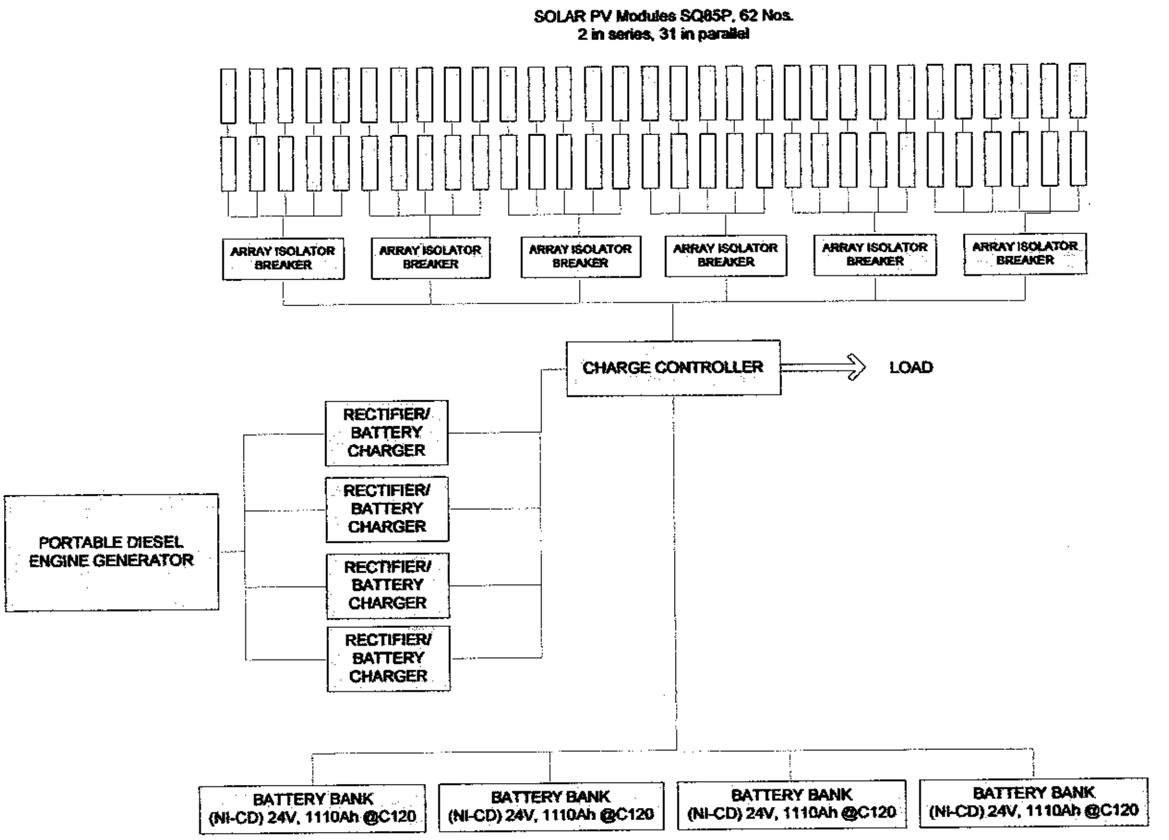


Figure 11 : Block Diagram for Instrumentation and Telecommunication System (System IIA)

4.8.3 Instrumentation and Telecommunication System (System IIB)

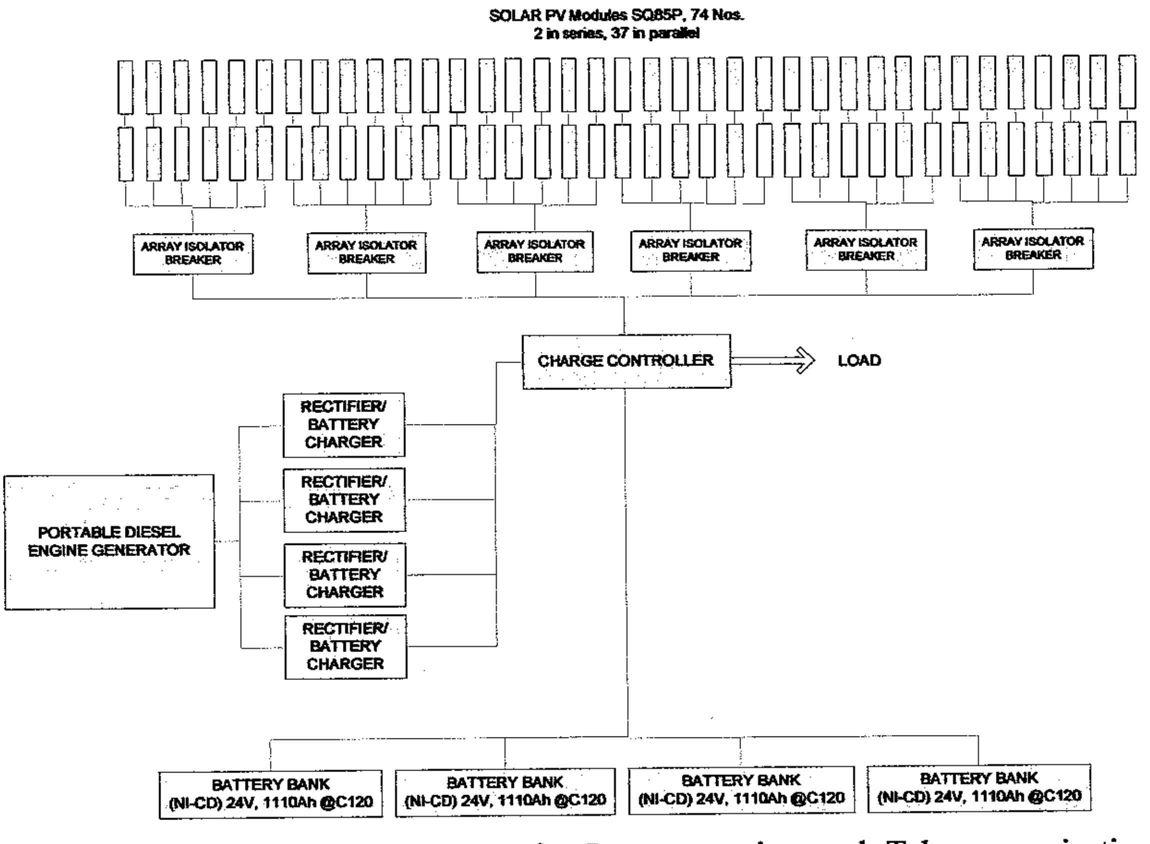


Figure 12 : Block Diagram for Instrumentation and Telecommunication System (System IIB)

4.8.4 Navaids System (System III)

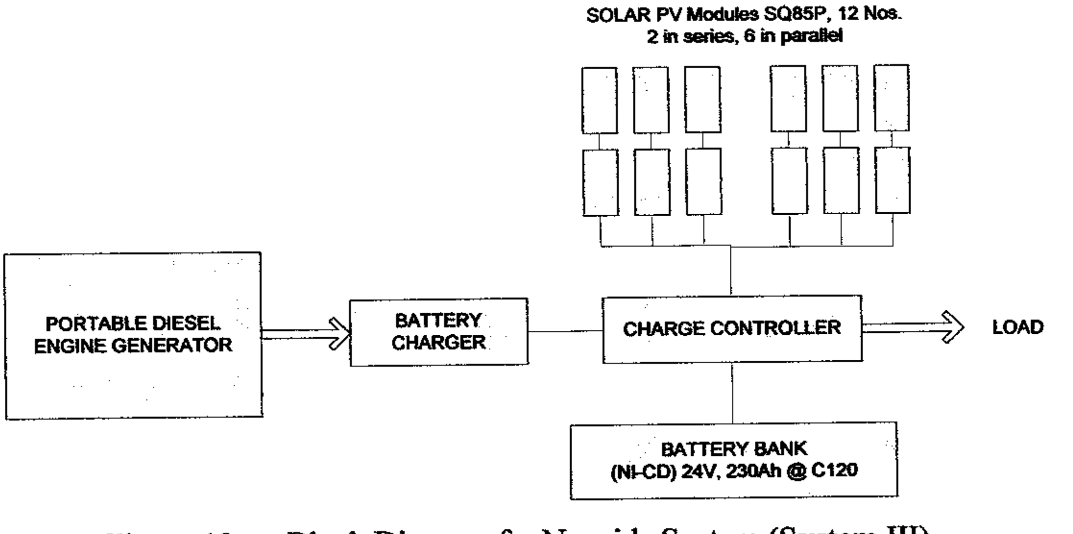


Figure 13 : Block Diagram for Navaids System (System III)

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The solar power system designed is reliable and practical as it is designed with real loads used in offshore platform. The hybrid solar power system is identified to be the most suitable type of solar power system to be installed at offshore platform, specifically MTA Platform. The hybrid solar power system consists of solar panel as a photovoltaic generator, battery as storage system, charge regulator as power conditioning unit and portable diesel generator as back-up power supply. The permanent power during normal operations will be solar panels to supply power to DC loads while during manned operation portable diesel generator will supply power to the AC loads.

The solar power system designed meets the DC load requirements at the MTA Platform as the design is based on the real situation of the platform using the real data. The total DC load required at the MTA Platform is 21540 watt-hour per day or 897.49 Ampere-hour per day for all four systems. The designed solar power system was sized based on the loads required. The design is reliable as it is designed to be able to supply the loads with solar energy which is abundant in supply and does not require much maintenance and can supply energy for up to 14 hours for System I and 7 days for System IIA, System IIB and System III during low insolation.

The solar panel used in this solar power system is from mono-crystalline type which is higher in efficiency compared to other types of solar panels such as poly-crystalline or amorphous thin film. The solar panels were sized based on Shell

PowerMax™Ultra 85-P solar modules. Shell PowerMax™Ultra 85-P solar module contains 36 series connected 125mm x 125mm mono-crystalline solar cells which can generate a peak power of 85 watts at 17.2 volts. The number of solar panels calculated for each system are; System I – 4, System IIA – 62, System IIB – 74, System III – 12, which total up to 152 number of solar panels. Array capability for each system is capable of supplying the loads needed.

The storage system for this solar power system use battery from nickel cadmium type. The correct choice of battery energy storage is crucial in order to ensure the efficiency of the solar power system. This solar power system needs battery storage system that withstand absolute reliability with minimal maintenance, operations with erratic charging conditions, good cycling ability that can have 20 years design life. The battery was sized based on Sunica.plus nickel cadmium battery. From the calculation, the battery capacity obtained for each system are; System I – 213 Ah, System IIA – 4400 Ah, System IIB – 4400 Ah, System III – 645 Ah. From calculations and based on Sunica.plus battery catalogue, System I uses cell type of SUN+230, System IIA and System IIB use SUN+1110 cell type and System III uses SUN+645. All selected battery capacity is able to provide power to the loads during low insolation for the specified autonomy period.

5.2 Recommendation

Based on works performed, there are some recommendations for future studies and further improvement of the system. A user friendly design tool program can be done in order to ease the calculation instead of Microsoft Excel. The program can be used as a guide in designing solar power system for offshore platform. The new user can just simply use the program to have an overview and size of solar panel and battery required for specified requirement. The user can just simply insert the loads required and choose the type of solar panel or battery required and no need to worry about the calculation as the program will do it for the user. In this case, it will be much simpler and easy for user instead of using the Microsoft Excel Spreadsheet.

The AC system can also be included in the system as an addition to DC loads. If AC loads is to be added to the system, a separate inverter must be included in order to convert the DC power produced by solar panel to AC power needed by the loads.

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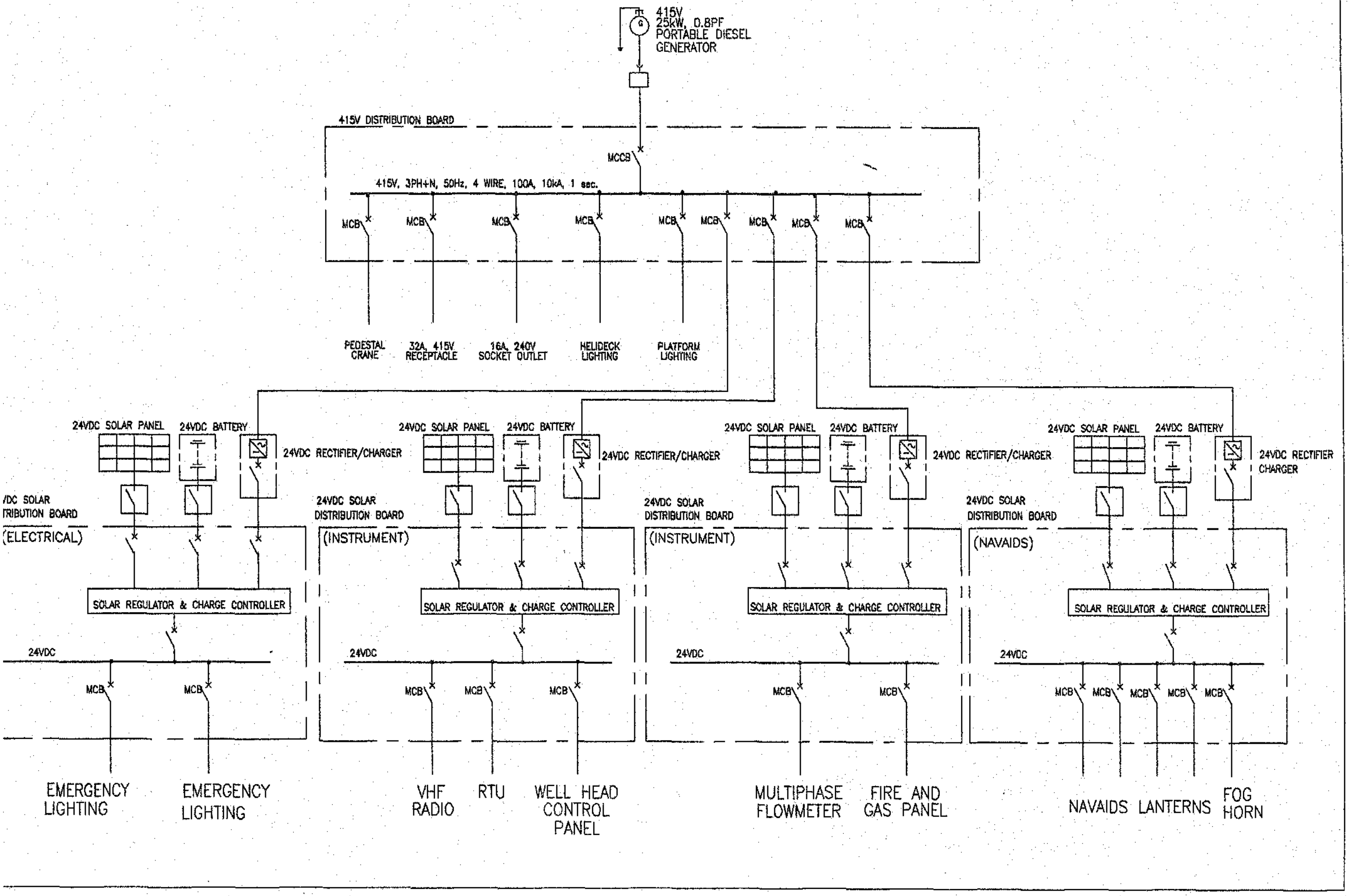
[11] Steve Harrington, Ktech Corporation and James Dunlop, *"Battery charge controller characteristics in photovoltaics system"*, Florida Solar Energy Center

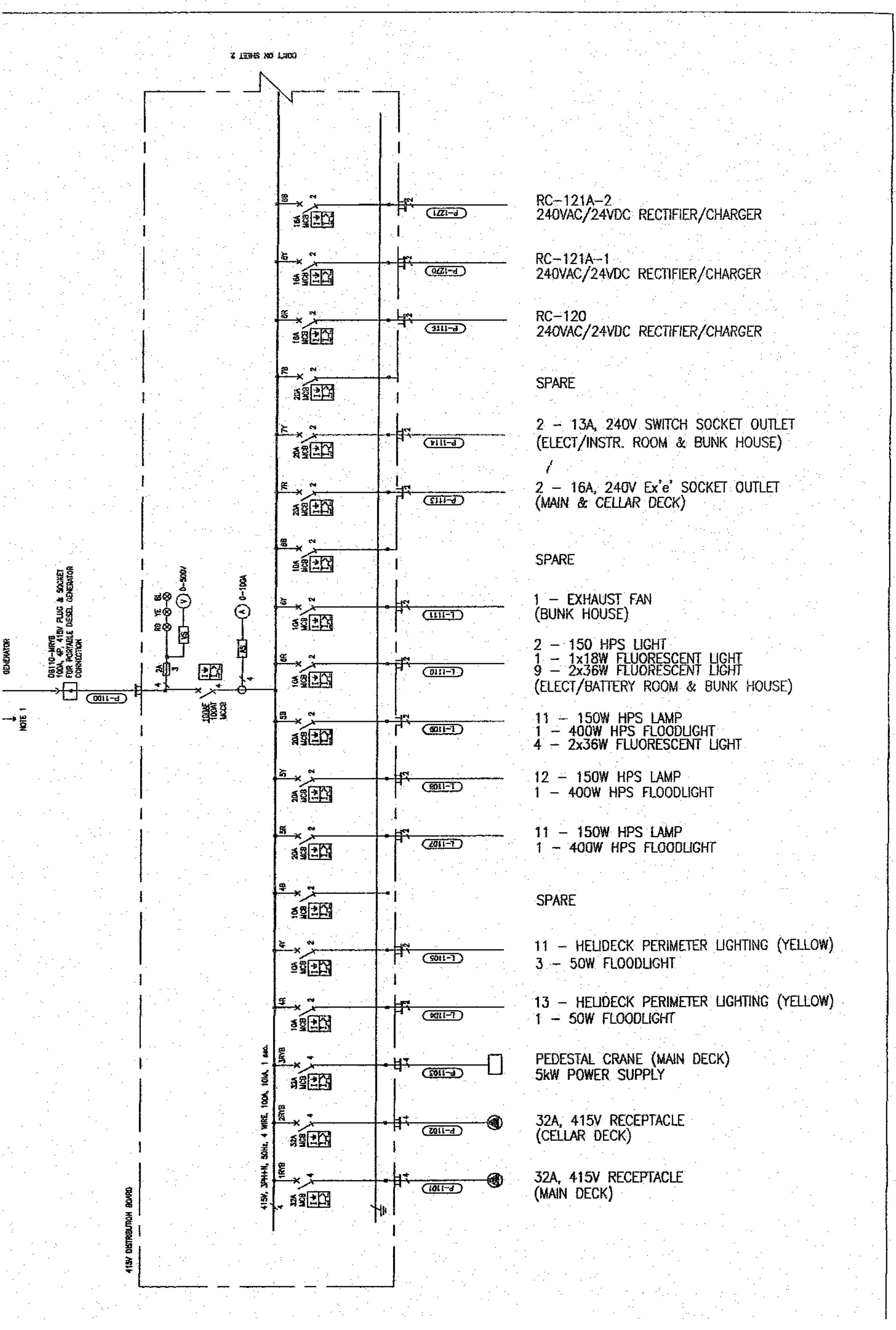
APPENDICES

APPENDIX A

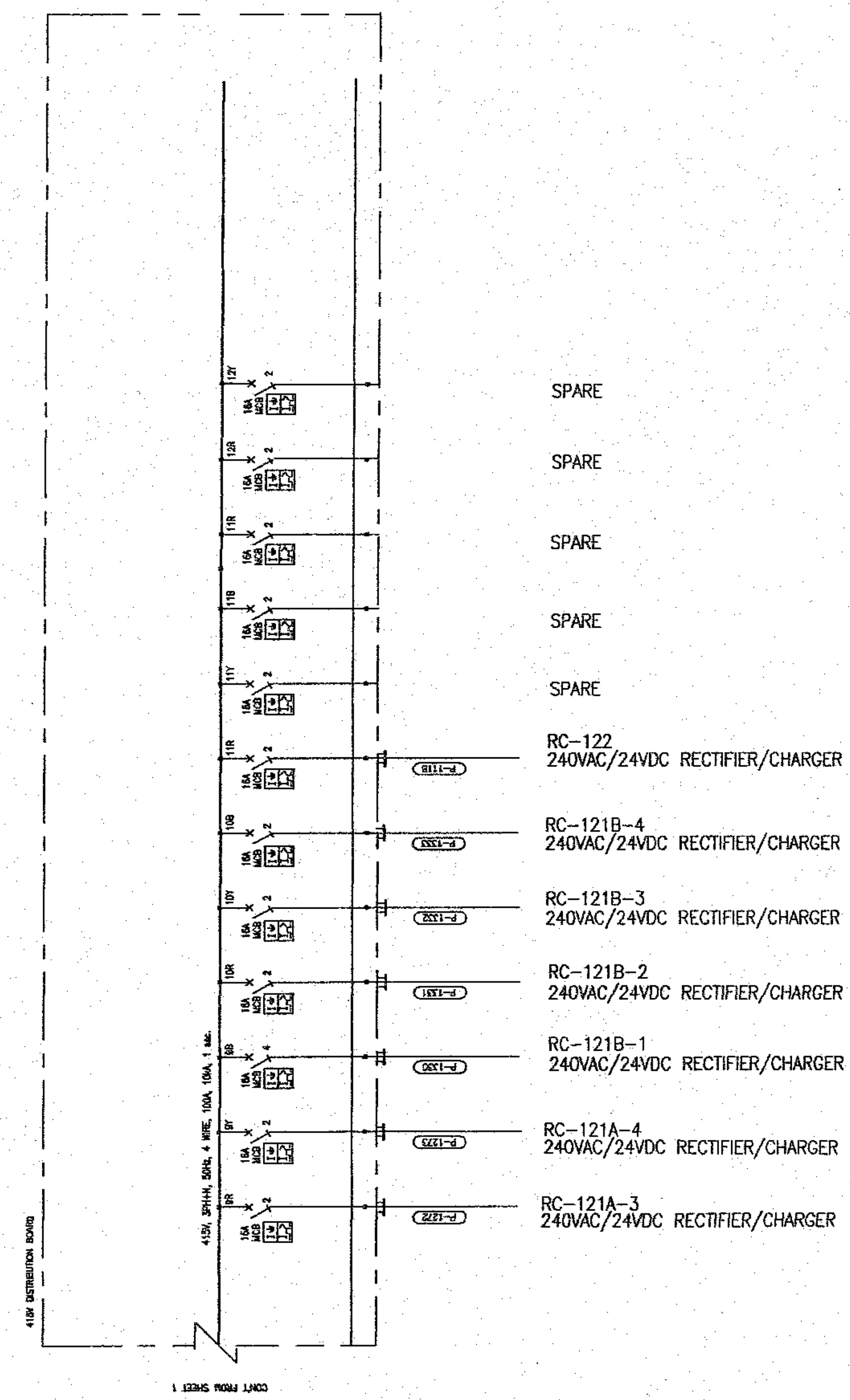
SINGLE LINE DIAGRAM



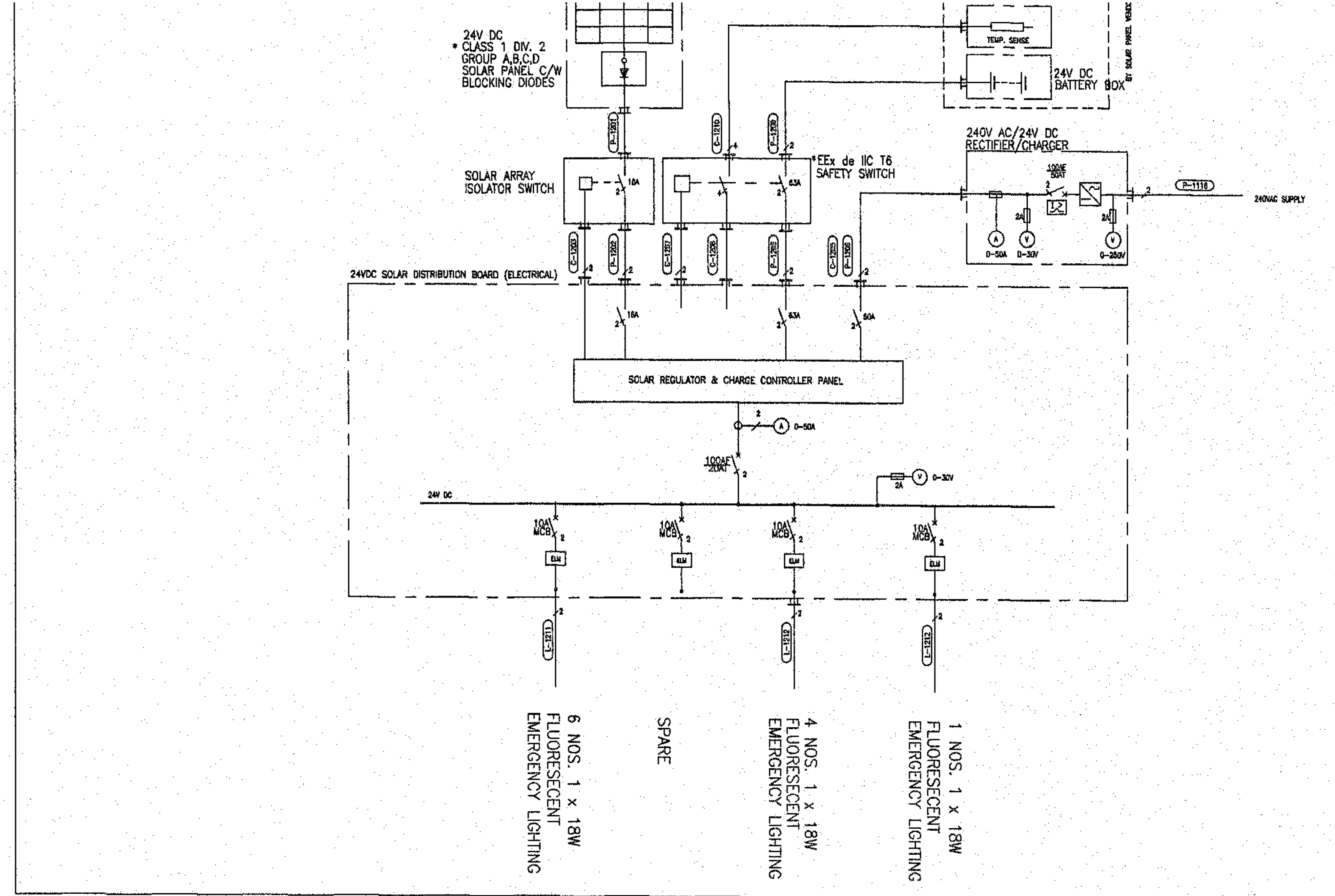
OVERALL SINGLE LINE DIAGRAM



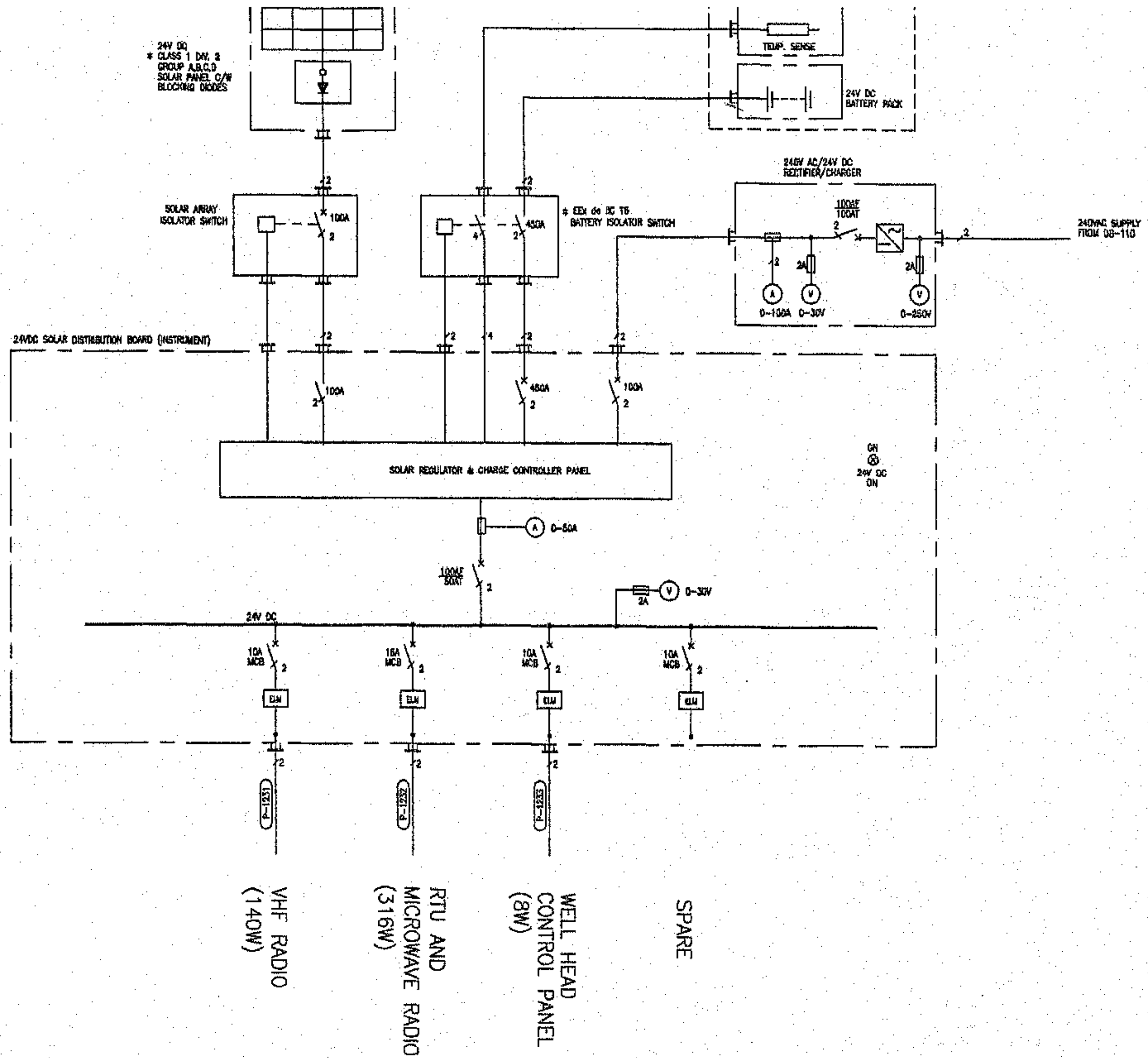
RC-121A-2
240VAC/24VDC RECTIFIER/CHARGER
RC-121A-1
240VAC/24VDC RECTIFIER/CHARGER
RC-120
240VAC/24VDC RECTIFIER/CHARGER
SPARE
2 - 13A, 240V SWITCH SOCKET OUTLET
(ELECT/INSTR. ROOM & BUNK HOUSE)
2 - 16A, 240V Ex'e' SOCKET OUTLET
(MAIN & CELLAR DECK)
SPARE
1 - EXHAUST FAN
(BUNK HOUSE)
2 - 150 HPS LIGHT
1 - 1x18W FLUORESCENT LIGHT
9 - 2x36W FLUORESCENT LIGHT
(ELECT/BATTERY ROOM & BUNK HOUSE)
11 - 150W HPS LAMP
1 - 400W HPS FLOODLIGHT
4 - 2x36W FLUORESCENT LIGHT
12 - 150W HPS LAMP
1 - 400W HPS FLOODLIGHT
11 - 150W HPS LAMP
1 - 400W HPS FLOODLIGHT
SPARE
11 - HELIDECK PERIMETER LIGHTING (YELLOW)
3 - 50W FLOODLIGHT
13 - HELIDECK PERIMETER LIGHTING (YELLOW)
1 - 50W FLOODLIGHT
PEDESTAL CRANE (MAIN DECK)
5kW POWER SUPPLY
32A, 415V RECEPTACLE
(CELLAR DECK)
32A, 415V RECEPTACLE
(MAIN DECK)
GENERATOR
NOTE 1
0-500V
0-100A
415V DISTRIBUTION BOARD



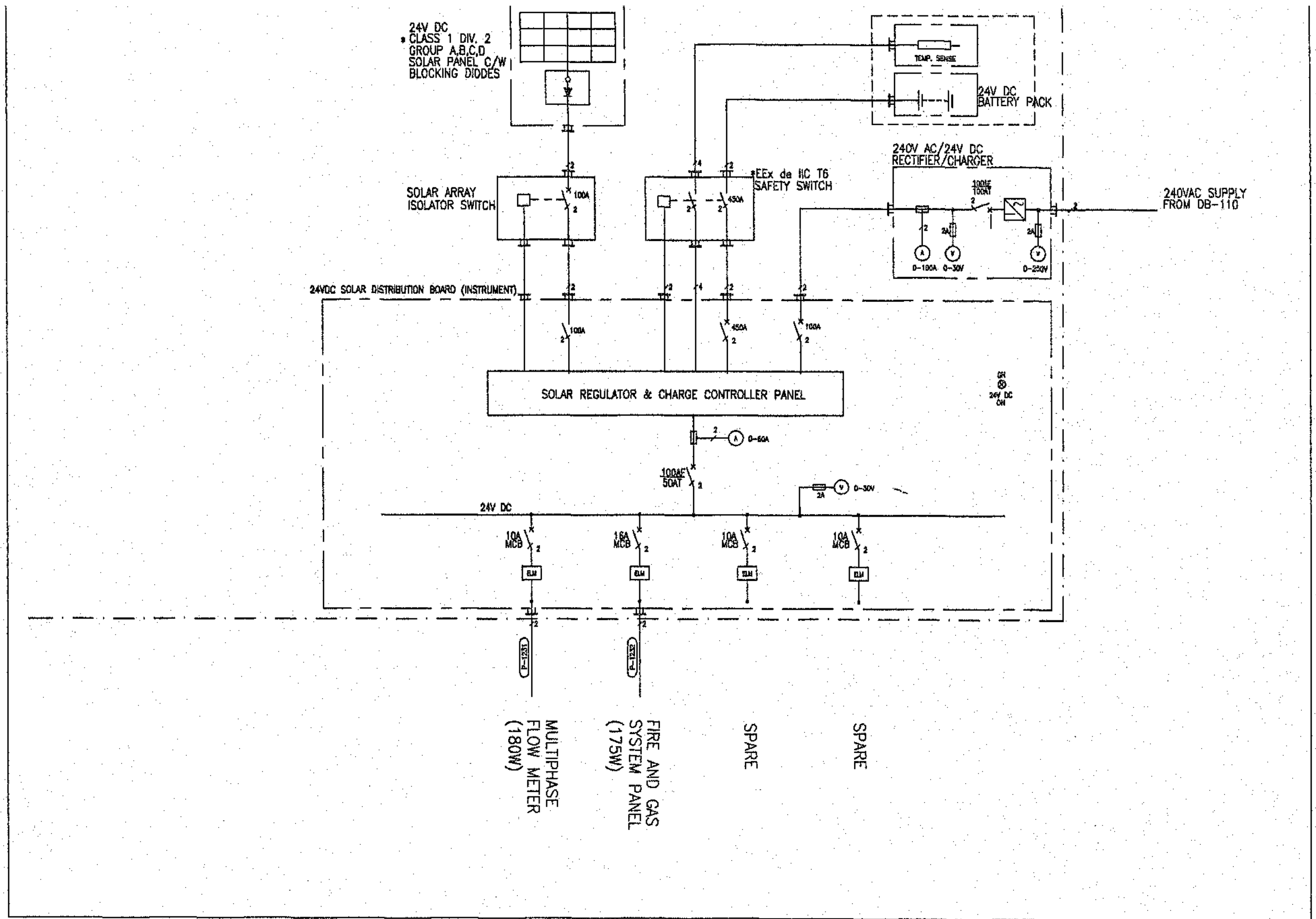
AC LOADS (cont.)



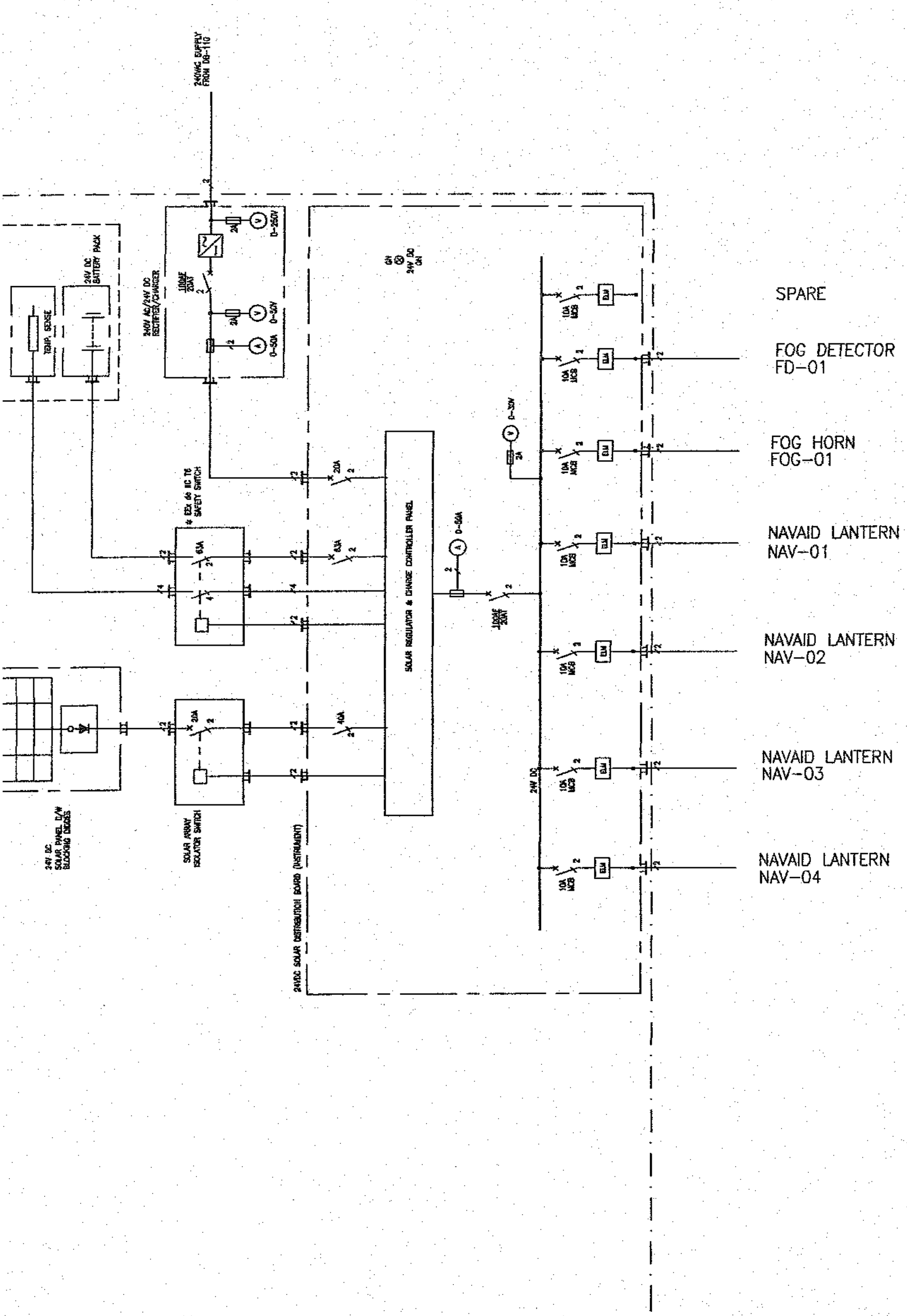
SYSTEM I: ELECTRICAL SYSTEM



SYSTEM IIA : INSTRUMENTATION AND TELECOMMUNICATION SYSTEM



SYSTEM IIB: INSTRUMENTATION AND TELECOMMUNICATION SYSTEM



SYSTEM III: NAVAIDS SYSTEM

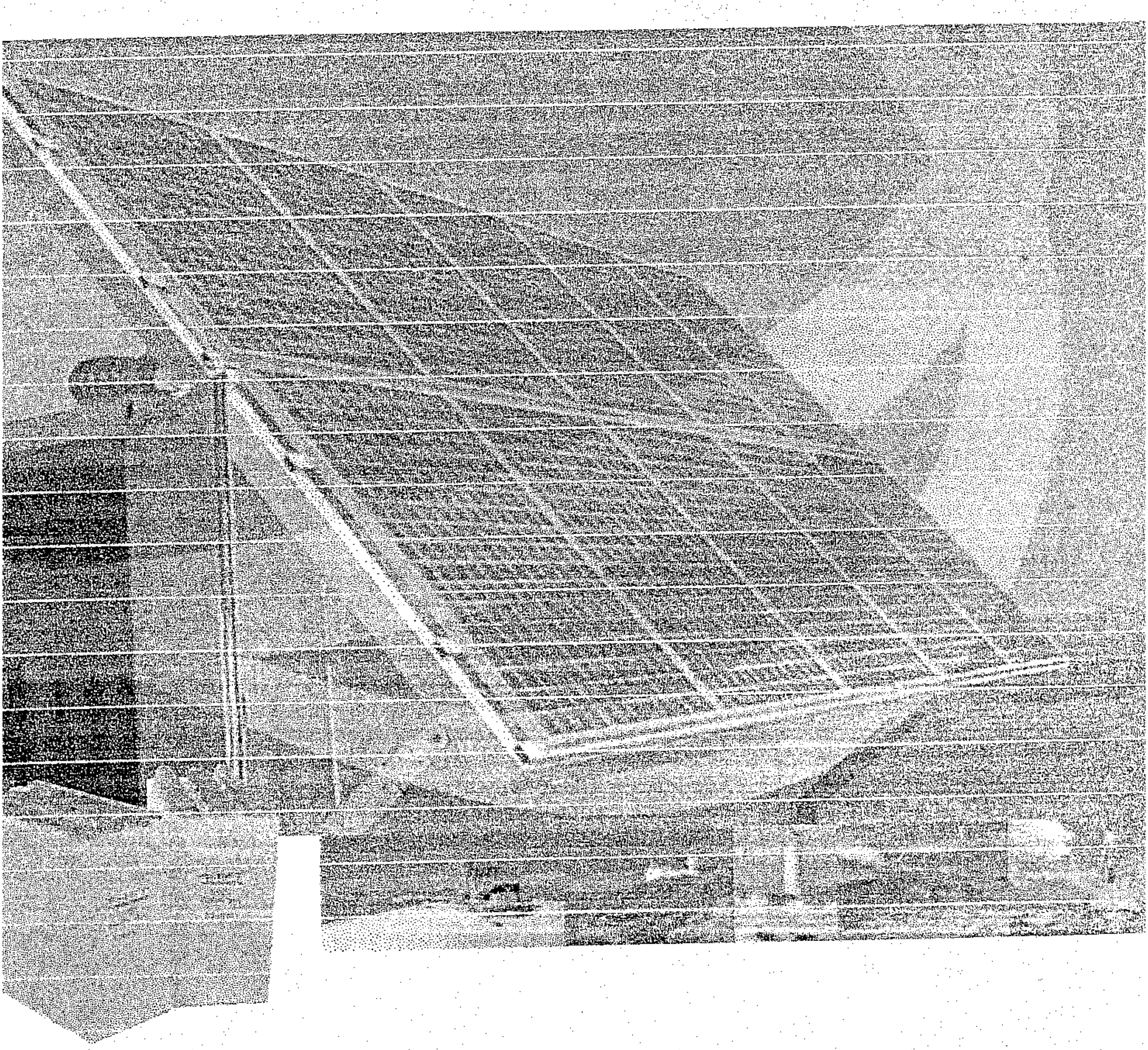
APPENDIX B
INSOLATION DATA

MONTH	INSOLATION (10° SOUTH FACING) (KWH/M^2/DAY)
JANUARY	5.64
FEBRUARY	6.13
MARCH	6.64
APRIL	6.90
MAY	6.78
JUNE	4.88
JULY	4.09
AUGUST	3.86
SEPTEMBER	4.55
OCTOBER	5.58
NOVEMBER	5.98
DECEMBER	5.49

APPENDIX C

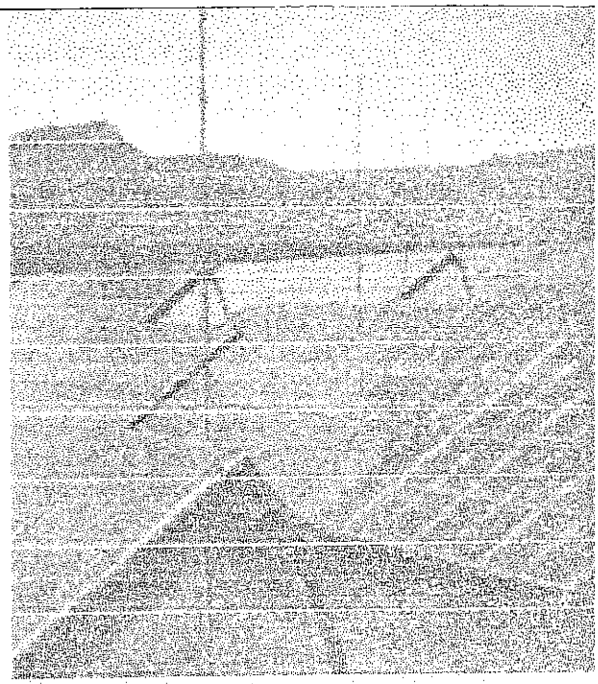
SUNICA.PLUS BATTERY CATALOGUE

nica.plus Ni-Cd batteries
tended capability for challenging photovoltaic conditions



ril 2004

erformance
yond conventional limits

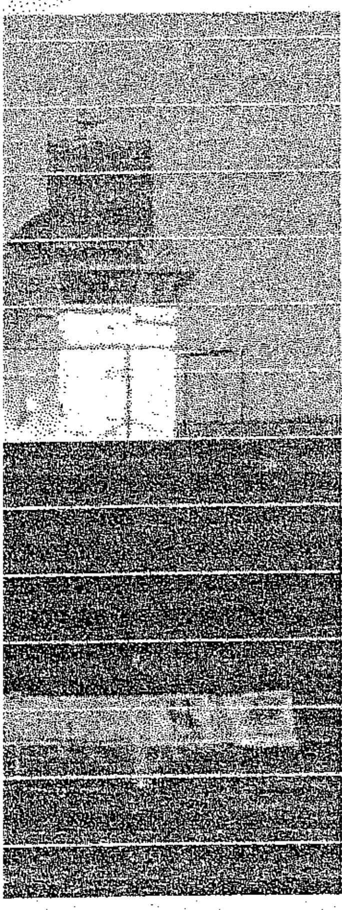


ted in the most punishing environments, photovoltaic :ations experience conditions for energy storage that only oughest battery can survive.

· the particular needs photovoltaic applications...

The correct choice of battery energy storage is crucial to enable photovoltaic system efficiency. To optimise performance, and to guarantee uninterrupted service, batteries must withstand –

- cycling at variable state of charge (SOC) and depth of discharge (DOD)
- operation with erratic charging conditions
- wide temperature fluctuations
- absolute reliability with minimal maintenance
- unpredictable demands in isolated locations
- physical and mechanical abuses
- complex patterns of shallow and deep discharges



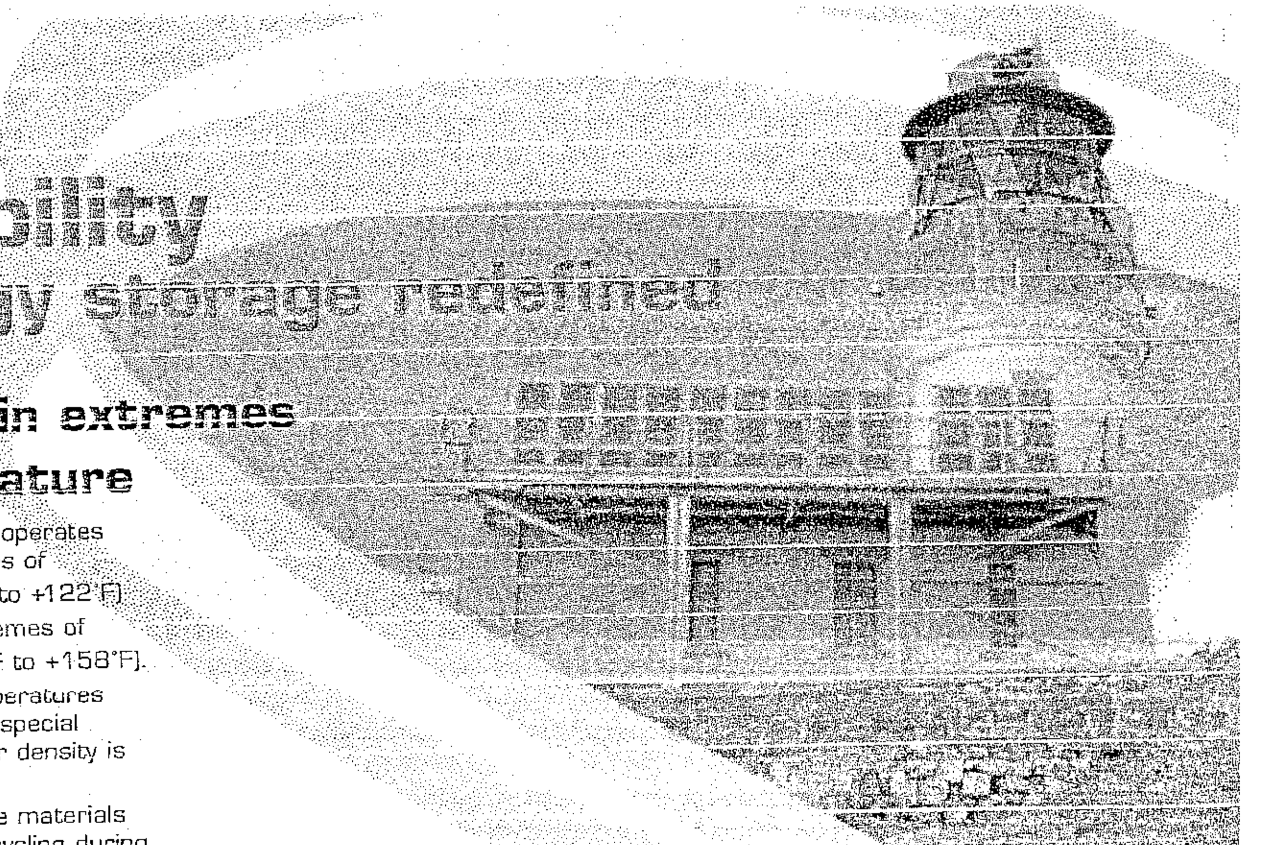
...the specialised solution is Sunica.plus Ni-Cd batteries...

Saft nickel-cadmium batteries are proven in the field of photovoltaics and are specified for their very broad capability and total reliability in uncertain conditions.

- corrosion-free steel internal construction, unaffected by alkaline electrolyte
- electrochemically stable during charge and discharge (no plate degradation)
- low life cycle cost
- 99.9% of metals used are recycled, safeguarding the environment

...for performance beyond the lead acid limit

- resistant to over- and under-charging, and complete discharge
- no premature capacity loss – sulphation – when cycled at low state of charge
- operates at temperatures lower than -20°C (-4°F) with no risk of freezing electrolyte



eliability

energy storage redefined

erates in extremes

temperature

ı.plus generally operates
en temperatures of
to +50°C (-4°F to +122°F)
n tolerate extremes of
to +70°C (-58°F to +158°F).
peration in temperatures
-20°C (-4°F), a special
olyte with higher density is

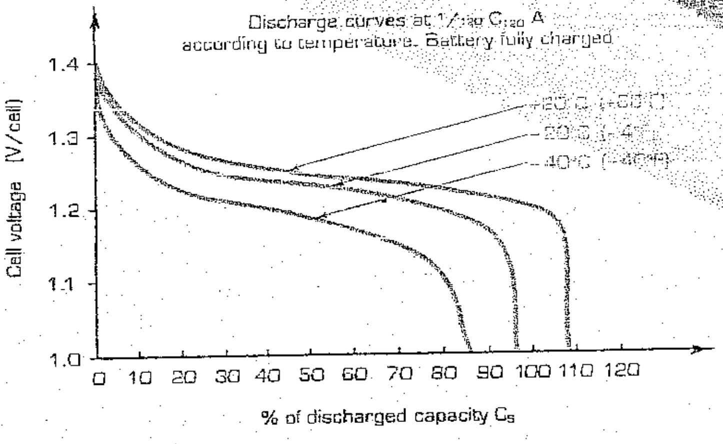
-cadmium active materials
n stable when cycling during
tates of charge and do not
active mass during deep
. Sunica.plus operates with –

isk of sudden death

late degradation or sulphation

e than 80% of capacity for a
cal 120 hour discharge at
C (-40°F)

20% decrease in life at +30°C
6°F), vs. 50% reduction for
acid



performs at any state of charge...

table alkaline electrolyte in Sunica.plus does not change during charge
ischarge. It continues to operate irrespective of the charge level and is
ected by accidental overcharge, deep discharges or inversion. During
itical winter months the charge efficiency is close to 100%.

achieves 8000 cycles at 5% depth of discharge

20°C (+68°F), Sunica.plus nickel-cadmium batteries can achieve –

to 8000 cycles at 15%
th of discharge during its 20
rs life

- good cycling ability in unstable
photovoltaic conditions, even at
partial state of charge

unica.plus is new

a heritage of long life,
ɔle, low maintenance
ow life cycle cost
:ions, Saft Sunica.plus
innovation in battery
nology for photovoltaics.

signed specifically for this application

.a.plus features Saft's highly ɛnt internal gas recombination ɛt plate technology – meets 2259 – and electrode design, ıised for photovoltaic :ations. These features, plus ently safe Ni-Cd, provide the naintenance service vital in ;ed locations.

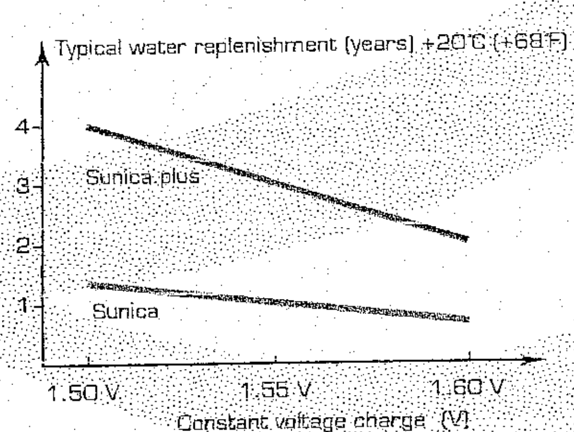
re than 4 years maintenance- ɛ intervals without topping-up, ɔending upon application juirements

npatible with all current ɔtovoltaic charge regulators

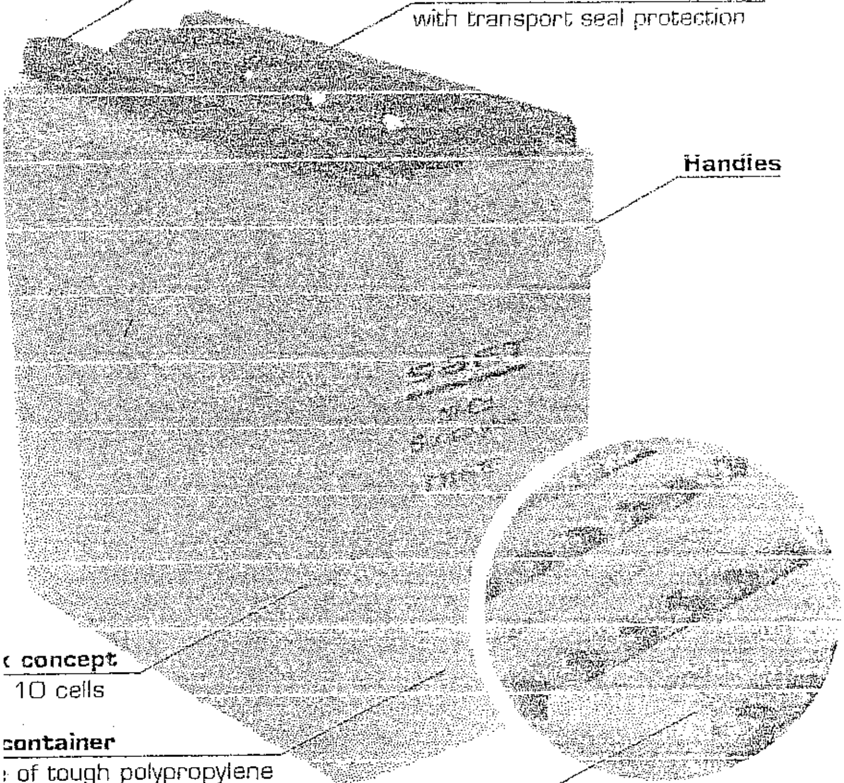
ɔroved cycling ability

Optimised for practical reliability

- robust construction withstands heavy treatment
- unaffected by fluctuating climatic conditions
- resistant to electrical abuses
- integrated handles mean easy handling
- easy to install, simple block construction



obustness
ıaranteed by design



automated integral water filling
m is available as an option for
a.plus cell types 185 Ah to 1110 Ah.

The main benefits of the system are:

- centrally monitors levels
- tops up accurately and efficiently when necessary
- enables gases generated to be evacuated outside the battery room

years low life cycle cost product

nbination of factors add up to give a predictably low life cycle cost.

- maintenance
- safe technology
- ı life time
- easy to install
- 12 months storage filled and charged, ready for immediate commissioning

20 years operation, typically cycling at an average 15% DOD, Saft
a.plus will rapidly repay initial battery investment and overall photovoltaic
n costs through autonomous operation and total reliability.

Where customers rely on Sunica

Around the coast of Scotland and the Isle of Man, 95 solar-powered land-based lighthouses have been equipped with Sunica batteries. Solar panels combined with a suitably sized and highly efficient 24 V battery can accumulate sufficient energy to ensure reliable signalling, even in the less sunny winter months.

An installation for Spencer Gulf telecasters in Australia comprised a 3 kW solar array supported by two 18 cell parallel strings of SUN 84-1 Sunica cells, each with a nominal capacity of 860 Ah. In 2001 a further 3kW solar array was installed together with another string of 18 SUN84-1 Sunica cells.

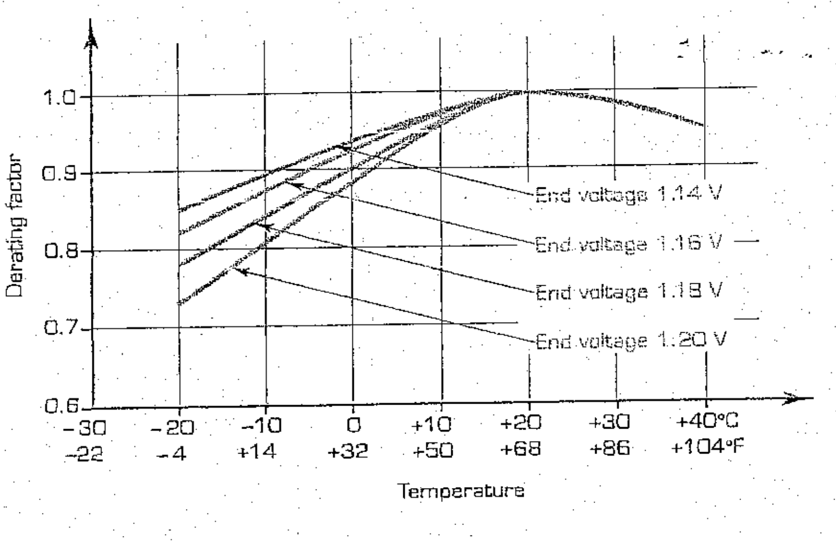
full range of solutions
r a world of photovoltaic needs

	Capacity		Height		Width		Length per block																		Weight	
	Ah	Ah	mm	in	mm	in	1 cell mm	in	2 cells mm	in	3 cells mm	in	4 cells mm	in	5 cells mm	in	6 cells mm	in	8 cells mm	in	9 cells mm	in	10 cells mm	in	per cell kg	lb
15	45	43	405	15.9	195	7.68					88	3.46	113	4.49	137	5.39	162	6.38	212	8.35	237	9.33	261	10.3	3.2	7.06
90	90	85	405	15.9	195	7.68					121	4.76	157	6.18	192	7.56	228	8.98	300	11.8	336	13.2	371	14.6	4.9	10.8
105	105	100	405	15.9	195	7.68					157	6.18	205	8.07	252	9.92	300	11.8	396	15.6	444	17.5			6.2	13.7
140	140	126	405	15.9	195	7.68					157	6.18	205	8.07	252	9.92	300	11.8	396	15.6					6.7	14.8
185	185	171	405	15.9	195	7.68					193	7.60	253	9.96	312	12.3	372	14.7							8.4	19.5
230	230	213	405	15.9	195	7.68			159	6.26	232	9.13	305	12.0	377	14.8									9.9	21.8
275	275	256	405	15.9	195	7.66			183	7.21	268	10.6	353	13.9	437	17.2									11.5	25.4
320	320	300	405	15.9	195	7.68			228	8.98	338	13.2													15.1	33.3
370	370	341	405	15.9	195	7.68			252	9.92	372	14.7													16.8	37.0
415	415	384	405	15.9	195	7.68	146	5.75	278	11.0															18.3	40.4
460	460	427	405	15.9	195	7.68	159	6.26	304	12.0															19.8	43.7
505	505	469	405	15.9	195	7.68	171	6.73	328	13.0															21.4	47.2
555	555	512	405	15.9	195	7.68	183	7.21	353	13.9															23.0	50.7
645	645	597	405	15.9	195	7.68	219	8.62																	28.2	62.2
735	735	682	405	15.9	195	7.68	244	9.61																	31.3	69.0
830	830	768	405	15.9	195	7.68	268	10.6																	34.5	76.1
920	920	853	405	15.9	195	7.68	304	12.0																	39.6	87.3
1110	1110	1024	405	15.9	195	7.68	352	13.9																	46.0	101

:a.plus complies with IEC 62259 standard.

ating factor according to temperature and end voltage

ypical solar application with
ys or more backup time



performance

ly charged cells after a constant current charge according to IEC 62259 standard.

s / h = hours

	End voltage = 1.14 V									End voltage = 1.16 V								
	2 d 48 h	3 d 72 h	4 d 96 h	5 d 120 h	6 d 144 h	7 d 168 h	8 d 192 h	9 d 216 h	10 d 240 h	2 d 48 h	3 d 72 h	4 d 96 h	5 d 120 h	6 d 144 h	7 d 168 h	8 d 192 h	9 d 216 h	10 d 240 h
5	0.94	0.64	0.48	0.39	0.33	0.28	0.25	0.22	0.20	0.92	0.63	0.47	0.39	0.33	0.28	0.25	0.22	0.20
0	1.86	1.26	0.95	0.77	0.65	0.56	0.49	0.44	0.40	1.82	1.25	0.94	0.77	0.64	0.56	0.49	0.44	0.40
05	2.19	1.49	1.11	0.90	0.76	0.66	0.58	0.52	0.47	2.15	1.47	1.10	0.90	0.76	0.65	0.58	0.52	0.47
40	2.80	1.90	1.43	1.15	0.98	0.85	0.74	0.66	0.60	2.75	1.88	1.41	1.15	0.97	0.84	0.74	0.66	0.60
85	3.74	2.54	1.91	1.54	1.31	1.13	0.99	0.89	0.80	3.67	2.52	1.89	1.54	1.29	1.12	0.99	0.89	0.80
30	4.66	3.17	2.37	1.92	1.63	1.41	1.23	1.10	0.99	4.57	3.14	2.35	1.92	1.61	1.39	1.23	1.10	0.99
75	5.60	3.80	2.85	2.30	1.96	1.69	1.48	1.33	1.19	5.49	3.77	2.83	2.30	1.94	1.68	1.48	1.33	1.19
20	6.58	4.46	3.34	2.70	2.29	1.98	1.73	1.56	1.40	6.44	4.42	3.31	2.70	2.27	1.96	1.73	1.56	1.40
70	7.46	5.07	3.80	3.07	2.60	2.25	1.97	1.77	1.59	7.32	5.02	3.77	3.07	2.58	2.23	1.97	1.77	1.59
15	8.40	5.71	4.28	3.46	2.93	2.54	2.22	1.99	1.79	8.24	5.65	4.24	3.46	2.91	2.51	2.22	1.99	1.79
60	9.34	6.35	4.76	3.84	3.26	2.82	2.47	2.21	1.99	9.16	6.29	4.71	3.84	3.23	2.80	2.47	2.21	1.99
05	10.26	6.97	5.23	4.22	3.58	3.10	2.71	2.43	2.19	10.06	6.90	5.18	4.22	3.55	3.07	2.71	2.43	2.19
55	11.20	7.61	5.71	4.61	3.91	3.38	2.96	2.65	2.39	10.99	7.54	5.65	4.61	3.88	3.35	2.96	2.65	2.39
45	13.06	8.87	6.65	5.37	4.56	3.94	3.45	3.10	2.79	12.81	8.79	6.59	5.37	4.52	3.91	3.45	3.10	2.79
35	14.92	10.14	7.60	6.14	5.21	4.51	3.94	3.54	3.18	14.63	10.04	7.53	6.14	5.16	4.47	3.94	3.54	3.18
30	16.80	11.41	8.56	6.91	5.87	5.07	4.44	3.98	3.58	16.48	11.31	8.48	6.91	5.81	5.03	4.44	3.98	3.58
20	18.66	12.68	9.51	7.68	6.52	5.64	4.93	4.42	3.98	18.30	12.56	9.42	7.68	6.46	5.59	4.93	4.42	3.98
1110	22.40	15.52	11.41	9.22	7.82	6.77	5.92	5.31	4.78	21.97	15.08	11.31	9.22	7.75	6.70	5.92	5.31	4.78

	End voltage = 1.18 V									End voltage = 1.20 V								
	2 d 48 h	3 d 72 h	4 d 96 h	5 d 120 h	6 d 144 h	7 d 168 h	8 d 192 h	9 d 216 h	10 d 240 h	2 d 48 h	3 d 72 h	4 d 96 h	5 d 120 h	6 d 144 h	7 d 168 h	8 d 192 h	9 d 216 h	10 d 240 h
45	0.89	0.62	0.47	0.38	0.32	0.28	0.24	0.22	0.20	0.82	0.57	0.43	0.36	0.31	0.27	0.24	0.21	0.19
90	1.75	1.22	0.93	0.76	0.64	0.55	0.48	0.43	0.39	1.61	1.13	0.86	0.71	0.61	0.53	0.46	0.42	0.38
105	2.06	1.43	1.09	0.89	0.75	0.65	0.57	0.51	0.46	1.90	1.33	1.01	0.83	0.72	0.62	0.55	0.49	0.44
140	2.64	1.83	1.40	1.14	0.96	0.83	0.73	0.65	0.59	2.43	1.71	1.29	1.07	0.92	0.79	0.70	0.63	0.57
185	3.53	2.45	1.87	1.52	1.28	1.11	0.97	0.87	0.78	3.24	2.28	1.73	1.43	1.22	1.06	0.94	0.84	0.76
230	4.39	3.05	2.33	1.90	1.60	1.38	1.21	1.08	0.98	4.04	2.84	2.15	1.78	1.52	1.32	1.16	1.05	0.84
275	5.28	3.66	2.80	2.28	1.92	1.66	1.45	1.30	1.17	4.85	3.41	2.59	2.13	1.83	1.58	1.40	1.26	1.13
320	6.19	4.29	3.28	2.68	2.25	1.95	1.70	1.53	1.38	5.69	4.00	3.03	2.50	2.15	1.86	1.64	1.47	1.33
370	7.03	4.88	3.73	3.04	2.56	2.21	1.94	1.74	1.56	6.46	4.55	3.45	2.84	2.44	2.11	1.86	1.67	1.51
415	7.92	5.49	4.20	3.42	2.88	2.49	2.18	1.96	1.76	7.28	5.12	3.88	3.20	2.75	2.38	2.10	1.88	1.70
460	8.81	6.11	4.67	3.81	3.20	2.77	2.42	2.17	1.96	8.10	5.69	4.31	3.56	3.05	2.64	2.34	2.10	1.89
505	9.67	6.71	5.13	4.18	3.52	3.04	2.66	2.39	2.15	8.89	6.25	4.74	3.91	3.35	2.90	2.56	2.30	2.07
555	10.56	7.32	5.60	4.57	3.84	3.32	2.91	2.61	2.35	9.71	6.83	5.17	4.27	3.66	3.17	2.80	2.51	2.26
645	12.31	8.54	6.53	5.32	4.48	3.87	3.38	3.04	2.74	11.32	7.96	6.03	4.98	4.27	3.70	3.28	2.93	2.64
735	14.07	9.76	7.46	6.08	5.12	4.42	3.87	3.47	3.13	12.93	9.09	6.89	5.68	4.88	4.22	3.73	3.35	3.01
830	15.84	10.99	8.40	6.85	5.76	4.98	4.36	3.91	3.52	14.56	10.24	7.76	6.40	5.49	4.75	4.20	3.77	3.39
920	17.59	12.20	9.33	7.61	6.40	5.53	4.84	4.34	3.91	16.17	11.37	8.62	7.11	6.10	5.28	4.66	4.19	3.77
1110	21.12	14.65	11.20	9.13	7.68	6.64	5.81	5.21	4.69	19.41	13.65	10.35	8.53	7.32	6.34	5.60	5.03	4.52

ng

ind the optimum battery solution by calculating –

I load
x
1/temperature derating factor
x
1/charge derating factor*
x
requested design margin
=
rent value to select in the performance table

*pical value is 90% when using the recommended charge voltage

Recommended charge Voltage

Battery system		[illegible]	24 V	[illegible]
Number of cells		9	18	[illegible]
Daily Depth of Discharge (% of C...)	[illegible]	[illegible]	27 V	54 V
	10 to 15%	13.95 V	27.9 V	55.8 V
	15 to 25%	14.4 V	28.8 V	57.6 V

nitted to a clean environment

:akes seriously its responsibility to safeguard the environment.
veral sites worldwide, more than 99% of metals contained in the battery are recycled. This process safeguards valuable natural resources and is a service to customers that Saft will continue to offer for future generations.
To locate the nearest collection site, visit www.saftbatteries.com

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Republic
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420 281 080 120
420 281 080 119

ark
upply A/S,
roed
45 45 82 50 90
45 45 82 54 40

Finland
HansaBattery Oy,
Espoo
tel +358 9 260 65 292
fax +358 9 260 65 299

France
Division France,
Bagnolet
tel +33 1 49 93 19 18
fax +33 1 49 93 19 64

Germany
Saft Batterien GmbH,
Nürnberg
tel +49 911 94 174-0
fax +49 911 426 144

Hong Kong
Saft Ltd,
Kowloon
tel +852 2796 99 32
fax +852 2798 06 19

India sub continent
Export sales dpt,
Sweden
tel +46 491 680 00
fax +46 491 681 80

Italy
Saft Batterie Italia S.r.l.,
Segrate (Milano)
tel +39 02 89 28 07 47
fax +39 02 89 28 07 62

Japan
Sumitomo Corp.,
Tokyo
tel +81 3 5144 9082
fax +81 3 5144 9267

Korea
Enersys Korea Co. Ltd,
Kyunggi-Do
tel +82 2501 0033
fax +82 2501 0034

Mexico
Troop y Compania,
SA de CV, Mexico
tel +52 55 50 82 10 30
fax +52 55 50 82 10 39

Middle East
Saft Nife ME Ltd,
Limassol, Cyprus
tel +357 25 820040
fax +357 25 748492

Netherlands
Saft Batteries B.V.,
Haarlem
tel +31 23 750 5720
fax +31 23 750 5725

Norway
Saft AS, Osteras
tel +47 6716 4160
fax +47 6716 4170

Russia
ZAO Alcatel, Moscow
tel +7 095 937 0967
fax +7 095 937 0906

Singapore
Saft Batteries Pte Ltd,
Singapore
tel +65 6512 1500
fax +65 6749 7282,

Spain
Saft Baterias S.L.
San Sebatian de los Reyes
tel +34 916 59 34 80
fax +34 916 59 34 90

Sweden
Saft AB,
Oskarshamn
tel +46 491 680 00
fax +46 491 681 80

Switzerland
Statron AG,
Mägenwil
tel +41 62 887 4 887
fax +41 62 887 4 888

United Kingdom
Saft Ltd,
Harlow
tel +44 1279 772 550
fax +44 1279 420 909

USA
Saft America Inc.,
North Haven (CT)
tel +1 203 239 4718
fax +1 203 234 7598

Telecom applications
Valdosta (GA)
tel +1 229 245 2854
fax +1 229 247 8486

Venezuela
Corporación INTELEC C.A.,
Caracas
tel +58 212 9631122

:
ıstrial Battery Group
rue Sadi Carnot
70 Bagnolet – France
-33 1 49 93 19 18
+33 1 49 93 19 64

v.saftbatteries.com

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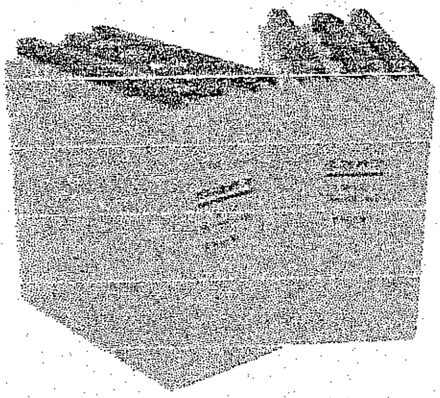
RCS Bobigny B 383 703 873

Prepared by Arthur Associates Limited.

ıica.plus Ni-Cd batteries

allation and operating instructions



tant recommendations

r allow an exposed flame or
k near the batteries
cularly while charging.

r smoke while performing any
ation on the battery.

protection, wear rubber gloves,
sleeves, and appropriate
sh goggles or face shield.

electrolyte is harmful to skin
eyes. In the event of contact
skin or eyes, wash immediately
plenty of water. If eyes are
cted, flush with water, and
in immediate medical attention.

ove all rings, watches and
r items with metal parts before
king on the battery.

insulated tools.

d static electricity and take
sures for protection against
tric shocks.

harge any possible static
tricity from clothing
/or tools by touching an
h-connected part "ground"
re working on the battery.

eceiving the shipment

k the battery immediately upon
l. Do not overturn the package.
the packages and cells for
port damage.

attery is shipped filled and
ed, and is ready for immediate

port seals are located under the
each vent, they must be removed
to mounting.

attery must never be charged
the plastic transport seals in
as this is dangerous and can
e permanent damage.

torage

the battery indoors in a dry,
, cool location (0°C to +30°C /
F to +86°F) and well ventilated
e on open shelves.

ige of a filled battery at
eratures above +30°C (+86°F)
result in loss of capacity. This can
s much as 5% per 10°C (18°F)
e +30°C (+86°F) per year.

ot store in direct sunlight or
se to excessive heat.

Sunica.plus batteries are supplied filled with electrolyte and charged, **they can be stored in this condition for maximum 12 months.**

Never drain the electrolyte from the cells.

- When deliveries are made in cardboard boxes, store without opening the boxes.
- **When deliveries are made in plywood boxes, open the boxes before the storage. The lid and the packing material on top of the cells must be removed.**

3. Installation

3.1. Location

Install the battery in a dry and clean room. Avoid direct sunlight and heat. The battery will give the best performance and maximum service life when the ambient temperature is between +10°C to +30°C / +50°F to +86°F.

3.2. Ventilation

During the last part of charging, the battery is emitting gases (oxygen and hydrogen mixture). At normal float charge, the gas evolution is very small but some ventilation is necessary.

Note that special regulations for ventilation may be valid in your area depending on the application.

3.3. Mounting

Verify that cells are correctly interconnected with the appropriate polarity. The battery connection to load should be with nickel plated cable lugs.

Recommended torques for terminal bolts are:

- M 6 = 11 ± 1.1 N.m
- M 8 = 20 ± 2 N.m
- M 10 = 30 ± 3 N.m

The connectors and terminals should be corrosion-protected by coating with a thin layer of anti-corrosion oil.

Remove the transport seals and close the vent caps.

If a central water filling system is used as an option, refer to the corresponding installation and operating instructions sheet.

3.4. Electrolyte

When checking the electrolyte levels, a fluctuation in level between cells is not abnormal and is due to the different amounts of gas held in the separators of each cell. The level should be at least 15 mm above the minimum level mark and there is normally no need to adjust it.

Do not top-up prior to initial charge.

4. Commissioning

A good commissioning charge is important. Charge at constant current is preferable.

4.1. Cells stored up to 6 months:

A commissioning charge is normally not required and the cells are ready for immediate use. If full performances are necessary immediately, a commissioning charge as mentioned in section 4.2. is recommended.

4.2. Cells stored more than 6 months and up to 1 year:

A commissioning charge is necessary.

Verify that the ventilation is adequate during this operation.

- charge at constant current for 16 h with the current in the Table A.
  Note that at the end of the charge period, the individual cell voltage may rise up to 1.85 V/cell.
- In case constant current charging is not providing, it is possible to achieve this with a constant voltage by using a high voltage level, minimum 1.65 V/cell for 30 hours with the same current limit as in the Table A.

When the charger maximum voltage setting is too low to supply constant current charging, divide the battery into two parts to be charged individually at constant current.

In the case of remote areas, where the only charger available is the photovoltaic array, the battery should be connected to the system with no connected load and no voltage limit. The battery should then be charged in good sunshine conditions. During this operation, the Ah charged shall be in the magnitude of 1.6 time the rated capacity, and, in order to limit the risk of electrolyte overflow, it is recommended not to exceed the charge current value specified in the Table A.

nica.plus Ni-Cd batteries

ıarging in service

ıotovoltaic array converts solar ınce into DC electrical power at a ıtermined range of voltages ıver sufficient solar radiation is ɔle. Unlike a main connected n, the output from a photovoltaic is variable and, to obtain the ıfficiency from the system, it is ıormal to have some form of ɜ control.

ıain technics for charging the ies are generally used in /oltaic systems.
are those which have a ɜnt voltage limitation based on /VM technics and those with ıl voltage steps charging where ıttery, by switching means, is ıng up to a high pre-set voltage ; or float threshold), then drops ıwer voltage level (battery ıect threshold) and then back high pre-set voltage and so on.

ımended charging voltages for a l photovoltaic application sized for s or more back up time:

e of constant voltage limitation
/VM regulator system or similar)
ɔat: 1.50 V/cell
ɔost (not mandatory): 1.65 V/cell

e of regulators based on the tching principle:
ɔost threshold (not mandatory):
.65 V/cell
ɔat threshold: 1.55 V/cell
ıttery reconnect threshold:
.45 V/cell

wer back-up time, the values ɔ be increased depending of the equirement. Consult the ıacturer.

ɜe in warm areas, a temperature ɜnsation on the charge voltage is ıcommended.
ɜe in cold areas, a temperature ɜnsation is recommended to ıse the charge acceptance.
ɜcommended value is:
mV/°C/cell (-1.4 mV/°F/cell)
ıg from +20°C (+68°F).

Table A:

Cell type	Rated Capacity 5 h - 1.00 V C_5 Ah	Nominal Capacity 120 h - 1.00 V C_{120} Ah Ah	Charging Current 0.1 C_5 A A	Max. quantity of water to be added in cc	Cell Terminal
SUN ⊕ 45	43	45	4.3	190	M 6
SUN ⊕ 90	85	90	8.5	280	M 8
SUN ⊕ 105	100	105	10	380	M 10
SUN ⊕ 140	128	140	13	380	M 10
SUN ⊕ 185	171	185	17	500	M 10
SUN ⊕ 230	213	230	21	590	M 10
SUN ⊕ 275	256	275	26	700	M 10
SUN ⊕ 320	300	320	30	860	2 x M10
SUN ⊕ 370	341	370	34	1000	2 x M10
SUN ⊕ 415	384	415	38	1100	2 x M10
SUN ⊕ 460	427	460	43	1200	2 x M10
SUN ⊕ 505	469	505	47	1300	2 x M10
SUN ⊕ 555	512	555	51	1400	2 x M10
SUN ⊕ 645	597	645	60	1700	3 x M10
SUN ⊕ 735	682	735	68	1900	3 x M10
SUN ⊕ 830	768	830	77	2100	3 x M10
SUN ⊕ 920	853	920	85	2400	4 x M10
SUN ⊕ 1110	1024	1110	102	2800	4 x M10

6. Periodic Maintenance

- In a correctly designed standby application, Sunica.plus requires the minimum of attention.

However, it is good practice with any system to carry out an inspection of the system once per year or at the recommended topping-up interval period to ensure that the charging system, the battery and the ancillary electronics are all functioning correctly.

- When this system service is carried out, it is recommended that the following actions should be taken:
  - cell electrolyte levels should be checked visually to ensure that the level is above the minimum and if necessary the cells should be topped up. Use only distilled or deionized water (see Table A for the quantity of water per cell).
  - the batteries should also be checked for external cleanliness, and if necessary cleaned with a damp brush using water. Do not use a wire brush or solvents of any kind. Vent plugs can be rinsed in clean water if necessary.
  - all the connectors must be tight. The connectors and terminal bolts should be corrosion-protected by coating with a thin layer of anti-corrosion oil.

7. Environment

To protect the environment all used batteries must be recycled. Contact your local Saft representative for further information.

strial Battery Group
ue Sadi Carnot
0 Bagnolet - France
33 1 49 93 19 18
33 1 49 93 19 64
saftbatteries.com

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APPENDIX D

SHELL POWERMAX™ SOLAR MODULES CATALOGUE

ell Solar
ll PowerMax™ solar modules
off-grid markets
on 2005

ral

erMax™ is a new range of
ble, high performance solar pro-
th designs created specifically
d applications.

erMax™Ultra 85-P and 80-P
contain 36 series connected
25mm mono-crystalline solar cells,
generate a peak power of 85 and
at 17.2 and 16.9 V respectively.

ications
ertificates

PowerMax™Ultra 85-P and 80-P
meet the following requirements:

215
ing 1703
proved
afety Class 2 (pending)

L) FM APPROVED TÜV CE

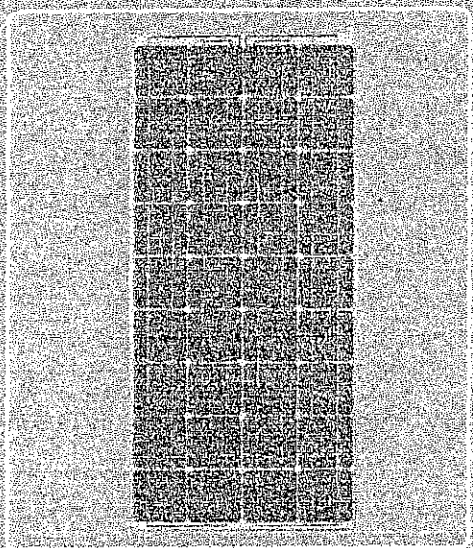
hell Solar modules are produced
01:2000 certified factories.

d Warranties*

wer for 25 years (category D).
workmanship 2 years.

ll Solar Limited Warranty
Modules

Shell PowerMax™ Ultra SQ85-P/80-P



ELECTRICAL EQUIPMENT, CHECK WITH YOUR INSTALLER

Due to continuous research and product improvement the specifications in this Product Information Sheet are subject to change without notice. Specifications can vary slightly. For installation and operation instructions, see the applicable manuals. No rights can be derived from this Product Information Sheet and Shell Solar assumes no liability whatsoever connected to or resulting from the use of any information contained herein.

References in this Product Information Sheet to 'Shell Solar' are to companies and other organisational entities within the Royal Dutch/Shell Group of Companies that are engaged in the photovoltaic solar energy business. Shell Solar was set up in 1999 and has its principal office in Amsterdam, the Netherlands.

The Shell PowerMax™ advantage

Exceptional Performance

- High efficiency crystalline silicon solar cell technology; enhanced by TOPS™ and new silicon nitride anti-reflection coatings.
- One of the industry's leading energy yields in a wide variety of climates.
- Products rated on fully stabilized initial power so you get the power you pay for.

Proven Reliability

- Module design proven over 30 years of field operations with reliability in excess of 99.9%.
- Extended limited power warranties backed by a company you can trust.
- UL 1703, IEC 61215, FM and TÜV Safety Class 2 certifications.

Safety by Design

- Suitable for high snow and wind loads.
- UL fire safety class C.

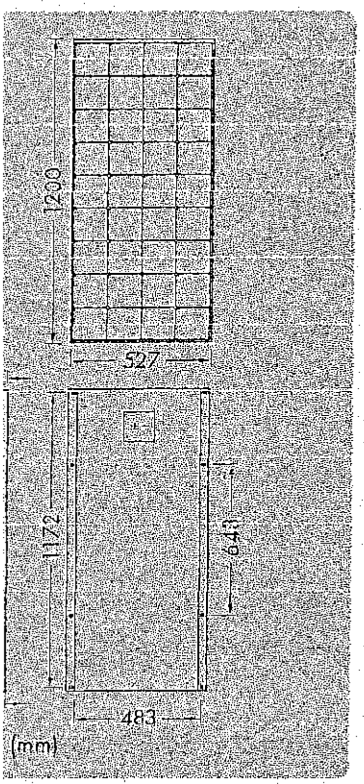
Easy to install

- Conduit ready junction box.
- 12 mounting holes per product; 4 grounding holes.
- 20A series fuse rating.

ell PowerMax™ Ultra SQ85-P/80-P
otovoltaic Solar Modules

anical fications

and corrosion-resistant anodized
ı frame ensures dependable
nce, even under harsh weather
s. Pre-drilled mounting holes are
for ease of installation.



nsions (in/mm)	47.2x20.8/1200x527
. junction box) (in/mm)	2.2/56
:. junction box) (in/mm)	1.3/34
g)	16.7/7.6
ype	ProCharger™ IP44
ize (in/mm)	5x4.4x1.8/130x110x50

n box allows for easy field
nt of diodes.

tion instructions, please
Shell Solar Installation and
uctions.

Electrical Characteristics

Data at Standard Test Conditions (STC)

STC: irradiance level 1000W/m², spectrum AM 1.5 and cell temperature 25°C.

	PowerMax™	Ultra 80-P	Ultra 85-P
Rated power [W]	P_r	80	85
Peak power* [W]	P_{mpp}*	80	85
Module efficiency [%]	η	12.7	13.4
Maximum system voltage	V_{sys}	600V (UL)/715V (TÜV)	600V (UL)/715V (TÜV)
Peak power voltage [V]	V_{mpp}	16.9	17.2
Peak power current [A]	I_{mpp}	4.76	4.95
Open circuit voltage [V]	V_{oc}	21.8	22.2
Short circuit current [A]	I_{sc}	5.35	5.45
Series fuse rating [A]	I_{fuse}	20	20
Minimum peak power [W]	$P_{mpp\ min}$	76	80.75
*Tolerance on Peak Power [%]	%	+/-5	+/-5

* The abbreviation 'mpp' stands for Maximum Power Point.

Typical Data at Nominal Operating Cell Temperature (NOCT) conditions

NOCT: irradiance level 800W/m², spectrum AM 1.5 , wind velocity 1m/s, T_{amb} 20°C.

Temperature [°C]	T_{NOCT}	45.5	45.5
Mpp power [W]	P_{mpp}	59	63
Mpp voltage [V]	V_{mpp}	15.8	16.4
Open circuit voltage [V]	V_{oc}	20.0	20.1
Short circuit current [A]	I_{sc}	4.20	4.25

Temperature coefficients

$\alpha\ P_{mpp}$ [%/°C]	-0,43	-0,43
$\alpha\ V_{mpp}$ [mV/°C]	-72.5	-72.5
$\alpha\ I_{sc}$ [mA/°C]	1.4	1.4
$\alpha\ V_{oc}$ [mV/°C]	-64.5	-64.5

Typical data at low irradiance

The relative reduction of module efficiency at an irradiance of 200W/m² in relation to 1000W/m² both at 25°C cell temperature and spectrum AM 1.5 is 8%.

For further information on all Shell Solar products contact:

Shell Solar Industries LLP
4650 Adhor Lane, Camarillo, CA 93012, USA
+1 805 482 6800 Fax +1 805 388 6395
solarsales@shell.com
www.shell.com/solar

Shell Solar GmbH
Domagkstr. 34, 80807 Munich, Germany
+49 89 45234 0 Fax +49 89 45234 100
solarinfo@shell.com

V1/PowerMax/Off-Grid12V/80-P/85-P/US/04/05

APPENDIX E

CALCULATION SHEETS

Load list for solar power system

ectrical Emergency Lighting (System I)

em o.	Description	Type of supply (V)	Unit load (watt)	Load quantity	Efficiency (%)		Total load (watt)		Daily duty cycle in hrs	Total load (Wh/day)	Total load (Ah/day)
1	Fluorescent emergency lighting	24	18	11	90		220		14	3080	128.3
	Total load per 24hr cycle						220			3080	128.3
	Design Margin					at	0	%		0	0
	Design Load per 24hr cycle						**220**			**3080**	**128.3**

trumentation and Telecommunication Power (System IIA)

m o.	Description	Type of supply (V)	Unit load (watt)	Load quantity	Efficiency (%)		Total load (watt)		Daily duty cycle in hrs	Total load (Wh/day)	Total load (Ah/day)
1	RTU and microwave radio	24	316	1	100		316		24	7584	316.0
2	Wellhead control panel	24	8	1	100		8		24	192	8.0
3	VHF Radio (crane)	24	140	1	100		140		0.857	120	5.0
	Total load per 24hr cycle						464			7896	329.0
	Design Margin					at	0	%		0	0
	Design Load per 24hr cycle						**464**			**7896**	**329.0**

trumentation and Telecommunication Power (System IIB)

m o.	Description	Type of supply (V)	Unit load (watt)	Load quantity	Efficiency (%)		Total load (watt)		Daily duty cycle in hrs	Total load (Wh/day)	Total load (Ah/day)
1	Multiphase Flow Meters	24	30	6	100		180		24	4320	180.0
2	Fire and Gas Panel	24	175	1	100		175		24	4200	175.0
	Total load per 24hr cycle						355			8520	355.0
	Design Margin					at	10	%		852	35.5
	Design Load per 24hr cycle						**390.5**			**9372**	**390.5**

arine Navaids (System III)

em o.	Description	Type of supply (V)	Unit load (watt)	Load quantity	Efficiency (%)		Total load (watt)		Daily duty cycle in hrs	Total load (Wh/day)	Total load (Ah/day)
1	Navaids Lanterns	24	2.65	4	100		10.6		16	169.6	7.07
2	Fog Horn	24	37.06	1	100		37.06		24	889.4	37.06
3	Fog Detector	24	5.56	1	100		5.56		24	133.4	5.56
	Total load per 24hr cycle						53.22			1192	49.69
	Design Margin					at	0	%		0	0
	Design Load per 24hr cycle						**53.22**			**1192**	**49.69**

Battery Sizing For System I

Equipment design calculation basis

Nominal system voltage	Vs	=	24 Vdc
Battery system capacity, % of total system requirements	Rb	=	100 %
Autonomy period	ts	=	14 hours
Ageing factor for battery capacity	kage	=	0.91 p.u.
Temperature correction factor for battery performance	kT	=	1 p.u.

Load data and derating

Average daily load	Qd1	=	128.3 Ah	(from load list)
Voltage regulator efficiency	η	=	92 %	
Average daily power consumption	Qd = Qd1/η	=	139.5 Ah	

Battery system sizing

Assumed daylight hours per day	td	=	10 hours
No of hours for which load is supplied by battery	(24-td)	=	14 hours
Total load demand over discharge period	Qs	=	139.5 Ah
Average discharge current per battery	Id' = Qs/ts	=	9.96 A
Maximum percentage discharge allowed (max DOD)	kd3	=	80 %
Required min battery capacity per battery system	Qb'=Qd/kd3/kage/kT	=	191.6
Actual selected battery capacity	Qb	=	213 Ah (C5)
Achieved system capability	Qb/Qb' *100	=	111 %
Achieved autonomy	Qb/Qd*kd3/100*ts*kage*kT	=	15.56 hours

Battery utilisation from initial nominal capacity

Distribution load per night cycle		=	139.5 Ah
Actual overnight depth of discharge	Qd1' = Qd/Qb*kT*100	=	65.49 %
Actual autonomy period, without derating	tsact = Qb/Qd*kT*ts	=	21.38 hours

Battery utilisation from aged capacity

Actual overnight depth of discharge	Qd1act = Qd1'/kage	=	71.97 %
Actual autonomy period to 100% discharge	tsact' = tsact*kage	=	19.45 hours

Solar Power Requirements

Minimum time to recharge from specified DOD			Tch	=	7 days		
Distribution load per discharge cycle				=	139.5 Ah	=	19.93 Ah per day
Battery recharge inefficiency loss at	7	% of cycle	Qbloss = Qd*7%	=	9.8 Ah	=	1.39 Ah per day
Daily battery self-discharge loss at	0.01	% of battery	Qbdisch = Qb*0.01%*Tch	=	0.1491 Ah	=	0.02 Ah per day
Total average solar energy requirements				=	149.4 Ah	=	21.34 Ah per day

tery Sizing For System IIA

ıipment design calculation basis

ninal system voltage	Vs	=	24 Vdc
tery system capacity, % of total system requirements	Rb	=	100 %
onomy period	ts	=	7 days
;ing factor for battery capacity	kage	=	0.91 p.u.
nperature correction factor for battery performance	kT	=	1 p.u.

ıd data and derating

;rage daily load	Qd1	=	329.0 Ah (from load list)
tage regulator efficiency	η	=	92 %
;rage daily power consumption	Qd = Qd1/η	=	357.6 Ah

teria 1 - Battery system sizing - daily load cycle

sumed daylight hours per day	td	=	8 hours
of hours for which load is supplied by battery	24-td	=	16 hours
;rage daily per battery load discharge	Qbd = (24-td)/24*Rb/100*Qd	=	238.4 Ah
ximum percentage discharge allowed	Kd1	=	20 %
tery size requirement	Qbd' = Qbd/(kd1/100)/kage/kT	=	1310 Ah

teria 2 - Battery system sizing - full discharge cycle

ly load demand on battery without solar array	Qs = Rb/100*Qd	=	357.6 Ah
;rage battery discharge current	Id = Qs/(24-td)	=	22.4 A
al battery load demand over discharge period	Qbs' = Qs*ts	=	2503.3 Ah
ximum percentage discharge allowed (max DOD)	kd3	=	80 %
tery size for max DOD from 100% charge	Qbc = Qbs'/(kd3/100)/kage/kT	=	3439 Ah
quired minimum battery capacity per battery system	Qb'=Max(Qbd,Qbc)	=	3439 Ah
tual battery capacity	Qb	=	4440 Ah (C120)
hieved system capability at specified autonomy of 7 days	Qb/Qb' *100	=	129.1 %
hieved autonomy		=	9.04 days

ttery utilisation from initial nominal capacity

stribution load per night cycle	QdLn = Qd*(24-td)/24	=	238.4 Ah
tual overnight depth of discharge	Qd1' = QdLn/(Qb*kT)*100	=	5.37 %
tual autonomy period without derating	tsact = Qb*kT/Qd	=	12.42 days

ttery utilisation from aged capacity

tual overnight depth of discharge	Qd1act = Qd1'/kage	=	5.90 %
tual autonomy period	tsact' = tsact*kage	=	11.3 days

lar Power Requirements

nimum time to recharge from specified DOD	Tch	=	28 days
ily night-time distribution load	QdLn	=	238.4 Ah
ily day-time distribution load	Qd' = td/24*Qd	=	119 Ah per daylight cycle
ttery recharge inefficiency loss at 7 % of cycle	Qbloss = 7% *QdLn	=	16.7 Ah per night cycle
ily battery self-discharge loss at 0.1 % of battery	Qbdisch = 0.1%*Qb	=	4.44 Ah per 24 hours
ily system energy requirements	Qd" = Qd+Qbloss+Qbdisch	=	378.7 Ah per 24 hours
ttery capacity to be recharged	Qbs' = Qs*ts	=	2503.3 Ah
ttery recharge inefficiency loss at 7 % of cycle	Qbloss' = 7%*Qbs'	=	175.2 Ah
ily recharge load from full discharge	Qchr = (Qbs'+Qbloss')/Tch	=	95.66 Ah
tal average solar energy requirements per 24 hour	Qchr + Qd"	=	474.4 Ah
		=	144 %

ıry Sizing For System IIB

pment design calculation basis

nal system voltage	Vs	=	24	Vdc
ry system capacity, % of total system requirements	Rb	=	100	%
ıomy period	ts	=	7	days
ıg factor for battery capacity	kage	=	0.91	p.u.
›erature correction factor for battery performance	kT	=	1	p.u.

l data and derating

age daily load	Qd1	=	390.5	Ah	(from load list)
ge regulator efficiency	η	=	92	%	
ıge daily power consumption	Qd = Qd1/η	=	424.5	Ah	

ıria 1 - Battery system sizing - daily load cycle

ımed daylight hours per day	td	=	8	hours
f hours for which load is supplied by battery	24-td	=	16	hours
ıge daily per battery load discharge	Qbd = (24-td)/24*Rb/100*Qd	=	283.0	Ah
ıum percentage discharge allowed	Kd1	=	20	%
ıry size requirement	Qbd' = Qbd/(kd1/100)/kage/kT	=	1555	Ah

ıria 2 - Battery system sizing - full discharge cycle

load demand on battery without solar array	Qs = Rb/100*Qd	=	424.5	Ah
ıge battery discharge current	Id = Qs/(24-td)	=	26.5	A
battery load demand over discharge period	Qbs' = Qs*ts	=	2971.2	Ah
mum percentage discharge allowed (max DOD)	kd3	=	80	%
ıry size for max DOD from 100% charge	Qbc = Qbs'/(kd3/100)/kage/kT	=	4081	Ah
ıired minimum battery capacity per battery system	Max(Qbd,Qbc)	=	4081	Ah
ıal battery capacity	Qb	=	4440	Ah (C120)
eved system capability at specified autonomy of 7 days		=	108.8	%
eved autonomy		=	7.6	days

ery utilisation from initial nominal capacity

ibution load per night cycle	QdLn = Qd*(24-td)/24	=	283.0	Ah
al overnight depth of discharge	Qd1' = QdLn/(Qb*kT)*100	=	6.37	%
al autonomy period without derating	tsact = Qb*kT/Qd	=	10.46	days

ery utilisation from aged capacity

ıal overnight depth of discharge	Qd1act = Qd1'/kage	=	7.00	%
ıal autonomy period	tsact' = tsact*kage	=	9.5	days

ır Power Requirements

mum time to recharge from specified DOD		Tch	=	28	days
y night-time distribution load		QdLn	=	283.0	Ah
y day-time distribution load		Qd' = td/24*Qd	=	141	Ah per daylight cycle
ery recharge inefficiency loss at	7 % of cycle	Qbloss = 7% *QdLn	=	19.8	Ah per night cycle
y battery self-discharge loss at	0.1 % of battery	Qbdisch = 0.1%*Qb	=	4.44	Ah per 24 hours
y system energy requirements		Qd" = Qd+Qbloss+Qbdisch	=	448.7	Ah per 24 hours
ery capacity to be recharged		Qbs' = Qs*ts	=	2971.2	Ah
ery recharge inefficiency loss at	7 % of cycle	Qbloss' = 7%*Qbs'	=	208.0	Ah
y recharge load from full discharge		Qchr = (Qbs'+Qbloss')/Tch	=	113.54	Ah
al average solar energy requirements per 24 hour		Qchr + Qd"	=	562.2	Ah
			=	144	%

ttery Sizing For System III

uipment design calculation basis

minal system voltage	Vs	=	24	Vdc
ttery system capacity, % of total system requirements	Rb	=	100	%
tonomy period	ts	=	7	days
eing factor for battery capacity	kage	=	0.91	p.u.
mperature correction factor for battery performance	kT	=	1	p.u.

ad data and derating

erage daily load	Qd1	=	49.7	Ah (from load list)
ltage regulator efficiency	η	=	92	%
erage daily power consumption	Qd = Qd1/η	=	54.0	Ah
y-time power consumption	Qd1	=	15.4	Ah
ght-time power consumption	Qd2	=	38.6	Ah

iteria 1 - Battery system sizing - daily load cycle

sumed daylight hours per day	td	=	8	hours
of hours for which load is supplied by battery	24-td	=	16	hours
erage daily per battery load discharge	Qbd = (24-td)/24*Rb/100*Qd	=	38.6	Ah
ximum percentage discharge allowed	Kd1	=	20	%
ttery size requirement	Qbd' = Qbd/(kd1/100)/kage/kT	=	212	Ah

iteria 2 - Battery system sizing - full discharge cycle

ily load demand on battery without solar array	Qs = Rb/100*Qd	=	54.0	Ah
erage battery discharge current	Id = Qs/(24-td)	=	3.4	A
tal battery load demand over discharge period	Qbs' = Qs*ts	=	378.1	Ah
ximum percentage discharge allowed (max DOD)	kd3	=	80	%
ttery size for max DOD from 100% charge	Qbc = Qbs'/(kd3/100)/kage/kT	=	519	Ah
quired minimum battery capacity per battery system	Max(Qbd,Qbc)	=	519	Ah
tual battery capacity	Qb	=	645	Ah (C120)
hieved system capability at specified autonomy of 7 days		=	124.2	%
hieved autonomy		=	8.7	days

ttery utilisation from initial nominal capacity

stribution load per night cycle	QdLn = Qd*(24-td)/24	=	36.0	Ah
tual overnight depth of discharge	Qd1' = QdLn/(Qb*kT)*100	=	5.58	%
tual autonomy period without derating	tsact = Qb*kT/Qd	=	11.94	days

ttery utilisation from aged capacity

tual overnight depth of discharge	Qd1act = Qd1'/kage	=	6.13	%
tual autonomy period	tsact' = tsact*kage	=	10.9	days

lar Power Requirements

inimum time to recharge from specified DOD	Tch	=	14	days
aily night-time distribution load	QdLn	=	38.6	Ah
aily day-time distribution load	Qd' = td/24*Qd	=	18	Ah per daylight cycle
attery recharge inefficiency loss at 7 % of cycle	Qbloss = 7% *QdLn	=	2.7	Ah per night cycle
aily battery self-discharge loss at 0.1 % of battery	Qbdisch = 0.1%*Qb	=	0.645	Ah per 24 hours
aily system energy requirements	Qd" = Qd+Qbloss+Qbdisch	=	57.4	Ah per 24 hours
attery capacity to be recharged	Qbs' = Qs*ts	=	378.1	Ah
attery recharge inefficiency loss at 7 % of cycle	Qbloss' = 7%*Qbs'	=	26.5	Ah
aily recharge load from full discharge	Qchr = (Qbs'+Qbloss')/Tch	=	28.89	Ah
otal average solar energy requirements per 24 hour	Qchr + Qd"	=	86.2	Ah
		=	174	%

Battery Sizing Summary

Design Load

System I	Electrical	=	128.3 Ah/day
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	329 Ah/day
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	390.5 Ah/day
System III	Navaids	=	49.69 Ah/day

Battery Size

System I	Electrical	=	213 Ah
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	4440 Ah
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	4440 Ah
System III	Navaids	=	645 Ah

Solar Energy Requirement

System I	Electrical	=	21.34 Ah/day
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	474.4 Ah/day
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	562.2 Ah/day
System III	Navaids	=	86.25 Ah/day

ectrical Solar Array System Sizing

ad Data

ominal system voltage	Vr	=	24 Vdc
ily load energy	Q	=	21.34 Ah

odule data

'arranted minimum power	Pmpp	=	85 W
ominal load current up to peak power voltage	Impp	=	4.95 A
mperature performance factor of efficiency	K_T	=	0.43 A/°C
lditional output due to Temperature correction	$K_T/100 \times (T_a-25)$	=	0.1505 A
ominal voltage	Vn	=	12 V

lar & Array sizing Data

quivalent sun hours (Note 1)	ESH	=	3.86 kWh/day/m²
o of series module connections per array	Ns=Vr/Vn	=	2
ell temperature (Note 2)	Ta	=	60 °C
geing, degradation, alignment, tilt and fouling factor (Note 3)	k_R	=	0.77
ngle module capability	Imod=[Impp*kR+(KT/100 x (Ta-25))] *ESH	=	15.2933 Ah/day
in no of modules per array	Nmin = Q/Imod*Ns	=	2.79 modules

ray capabilty

elected no of modules per array	Nact	=	4
apability of array	QA1 = Nact/Ns*Imod	=	30.5866 Ah/day
alculated system capability at actual load		=	143.3 %

otes:

) Based on insolation data for worst month (August)

) Average daily maximum for August

) 15 % for degradation
2 % for mis-alignment
1 % for fouling
2 % cell mismatch
3 % wiring/cabling losses

m IIA Solar Array System Sizing

Data

ıal system voltage	Vr	=	24 Vdc
oad energy	Q	=	474.40 Ah

le data

ınted minimum power	*Pmpp*	=	85 W
ıal load current up to peak power voltage	Impp	=	4.95 A
erature performance factor of efficiency	K_T	=	0.43 A/°C
onal output due to Temperature correction	$K_T/100 \times (T_a\text{-}25)$	=	0.1505 A
ıal voltage	Vn	=	12 V

& Array sizing Data

alent sun hours (Note 1)	ESH	=	3.86 kWh/day/m²
series module connections per array	Ns=Vr/Vn	=	2
emperature (Note 2)	Ta	=	60 °C
g, degradation, alignment, tilt and fouling factor (Note 3)	kR	=	0.77
module capability	Imod = [Impp*kR+(KT/100 x (Ta-25))] *ESH	=	15.2933 Ah/day
o of modules per array	Nmin = Q/Imod*Ns	=	62.04 modules

capabilty

ed no of modules per array	Nact	=	62
ility of array	QA1 = Nact/Ns*Imod	=	474.0929 Ah/day
ated system capability at actual load		=	99.9 %

:

Based on insolation data for worst month (August)
Average daily maximum for August

15 %	for degradation
2 %	for mis-alignment
1 %	for fouling
2 %	cell mismatch
3 %	wiring/cabling losses

em IIB Solar Array System Sizing

| Data

inal system voltage	Vr	=	24 Vdc
load energy	Q	=	562.25 Ah

ule data

anted minimum power	Pmpp	=	85 W
inal load current up to peak power voltage	Impp	=	4.95 A
ɔerature performance factor of efficiency	K_T	=	0.43 A/°C
itonal output due to Temperature correction	$K_T/100 \times (T_a-25)$	=	0.1505 A
inal voltage	Vn	=	12 V

r & Array sizing Data

valent sun hours (Note 1)	ESH	=	3.86 kWh/day/m²
f series module connections per array	Ns=Vr/Vn	=	2
temperature (Note 2)	Ta	=	60 °C
ng, degradation, alignment, tilt and fouling factor (Note 3)	kR	=	0.77
le module capability	Imod=[Impp*kR+(KT/100 x (Ta-25))] *ESH	=	15.2933 Ah/day
no of modules per array	Nmin = Q/Imod*Ns	=	73.53 modules

y capabilty

cted no of modules per array	Nact	=	74
ability of array	QA1 = Nact/Ns*Imod	=	565.8528 Ah/day
ulated system capability at actual load		=	100.6 %

s:

Based on insolation data for worst month (August)

Average daily maximum for August

15 %	for degradation
2 %	for mis-alignment
1 %	for fouling
2 %	cell mismatch
3 %	wiring/cabling losses

em III Solar Array System Sizing

I Data

inal system voltage	Vr	=	24 Vdc
load energy	Q	=	86.25 Ah

ule data

ranted minimum power	Pmpp	=	85 W
inal load current up to peak power voltage	Impp	=	4.95 A
perature performance factor of efficiency	K_T	=	0.43 A/°C
titonal output due to Temperature correction	$K_T/100 \times (T_a-25)$	=	0.1505 A
inal voltage	Vn	=	12 V

r & Array sizing Data

valent sun hours (Note 1)	ESH	=	3.86 kWh/day/m²
f series module connections per array	Ns=Vr/Vn	=	2
temperature (Note 2)	Ta	=	60 °C
ng, degradation, alignment, tilt and fouling factor (Note 3)	k_R	=	0.77
le module capability	Imod=[Impp*k_R+(K_T/100 x (Ta-25))] *ESH	=	15.2933 Ah/day
no of modules per array	Nmin = Q/Imod*Ns	=	11.28 modules

y capabilty

cted no of modules per array	Nact	=	12
ability of array	QA1 = Nact/Ns*Imod	=	91.7599 Ah/day
ulated system capability at actual load		=	106.4 %

es:

Based on insolation data for worst month (August)

Average daily maximum for August

15 %	for degradation
2 %	for mis-alignment
1 %	for fouling
2 %	cell mismatch
3 %	wiring/cabling losses

Solar Array Sizing Summary

Solar Energy Requirements

System I	Electrical	=	21.34 Ah/day
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	474.40 Ah/day
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	562.25 Ah/day
System III	Navaids	=	86.25 Ah/day

No of Solar panels

System I	Electrical	=	4 Nos
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	62 Nos
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	74 Nos
System III	Navaids	=	12 Nos
	TOTAL	=	152 Nos

Array Capability

System I	Electrical	=	30.59 Ah/day
System IIA	RTU/ Wellhead Control Panel/VHF Radio	=	474.09 Ah/day
System IIB	Multiphase Flow Meter/Fire & Gas Panel	=	565.85 Ah/day
System III	Navaids	=	91.76 Ah/day