THESIS

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A Graduation Project submitted in partial fulfillment of the Requirements for the degree of

Masters in mechanical engineering

Hybrid Power System

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LIST OF SYMBOLS

V	*VOLT*
A	*AMPERE*
W	*WATT*
m	*METER*
mm	*MILLIMETER*
h	*HOUR*
M	*MEGA*
V_{oc}	*Open Circuit Voltage*
I_{sc}	*Short Circuit Current*
I_{mp}	*Maximum Power Current*
ah	*Ampere Hour*
P_m	*Maximum Power*
V_r	*Rated Voltage*
V_c	*Cut-off Voltage*
V_f	*Failure Voltage*
RPM	*revolutions per minute*
in	*inch*
ms	*Milli second*

LIST OF ABBREVIATIONS

PV	*Solar Photovoltaics*
DC	*Direct Current*
AC	*Alternating Current*
BB	*Battery Bank*
PLC	*Programmable Logic Controller*
CPU	*Central Processing Unit*
VDC	*Voltage Direct Current*
VAC	*Voltage Alternating Current*
KWH	*Kilowatt Hour*
HPS	*Hybrid Power Supply*
Wp	*Watt Power*
KWp	*Kilo Watt Power*
LVD	*Low Voltage Disconnection*
BAT	*Battery*
DSL	*Diesel generator*
MW	*Megawatt*
WND	*Representing Wind in Hybrid Power Systems*
AREF	*analog Reference*
PWM	*Pulse-width modulation*
Kbyte	*kilo byte*
Mbyte	*Mega byte*
GHG	*Green House Gases*
GRD	*Grid*

CHAPTER 1 : INTRODUCTION

Clean energy has many benefits, such as having no emissions and being renewable, so they are a good alternative to conventional sources. On the other hand, there is an alternative way to use it, such as places where electricity is not always available or is affected by factors that are beyond control, like places with leakage of electricity, wars and natural disasters. Because of these problems, the need to provide electricity permanently is crucial in many critical facilities and devises, like hospital equipment, servers, banks, navigation equipment for aircraft control …etc. In addition, devices that are affected by power leakage, which pose a significant threat to human life and interests.

To solve this issue, a hybrid power system is needed. This system combines multiple clean energy sources with conventional sources to produce electricity. Such clean energy sources can be solar power, wind power, water, ...etc. These systems also use battery storage to ensure consistent energy availability to be supplied whenever needed, especially during uncontrolled factors such as natural disasters or grid system failure. The flexibility that this system offers makes it a suitable solution to safeguard important infrastructure and viable applications. In addition to that, using a hybrid power system helps reduce the dependence on fossil fuels and eventually reduce its environmental impact, by using and prioritizing clean non-harmful energy sources. Thus, this would help enhance energy security in regions and reach sustainability objectives.

therefore, in this research, it is decided to make a hybrid power supply, which can avoid the threats of unreliable grid infrastructure and electrical interruptions and provide critical and viable devices with electricity whenever it is needed.

Objectives of the study

- Design and enhance a hybrid power system, using the necessary calculations to produce sufficient energy and ensure compatibility
- Enhance reliability: to make sure the system provides continuous energy production or supply to necessary devices even during grid interruptions or bad weather
- Integration of clean energy: by using clean energy sources like solar panels and wind turbines

- Evaluation of performance of the system: by accessing the system efficiency and costs also.

Research Focus Questions

In order to achieve these objectives, the following points will be investigated:

- To determine the most effective setup of the system of renewable energy and conventional energy sources, with energy storage mechanisms like battery banks.
- To determine the configuration of the control system to easily transition between the different energy sources to supply the needed electricity efficiently
- How to guarantee the adaptability of the system to different conditions and facilitate the expansions for the future?
- What are the costs of implementing such a system in an area and what are the ecological and financial advantages?

CHAPTER 2 : LITERATURE REVIEW

2.1 The hybrid power systems

2.1.1 A wind-diesel hybrid power system

Wind-diesel (WND-DSL) hybrid power systems consist of wind turbines and diesel generators, which are used for different applications depending on the overall load requirements. Wind-diesel (WND-DSL) hybrid power systems with and without battery are presented in the following Figure 2-1. using a battery system enhances the performance and flexibility of the system especially during power outages [1][2].

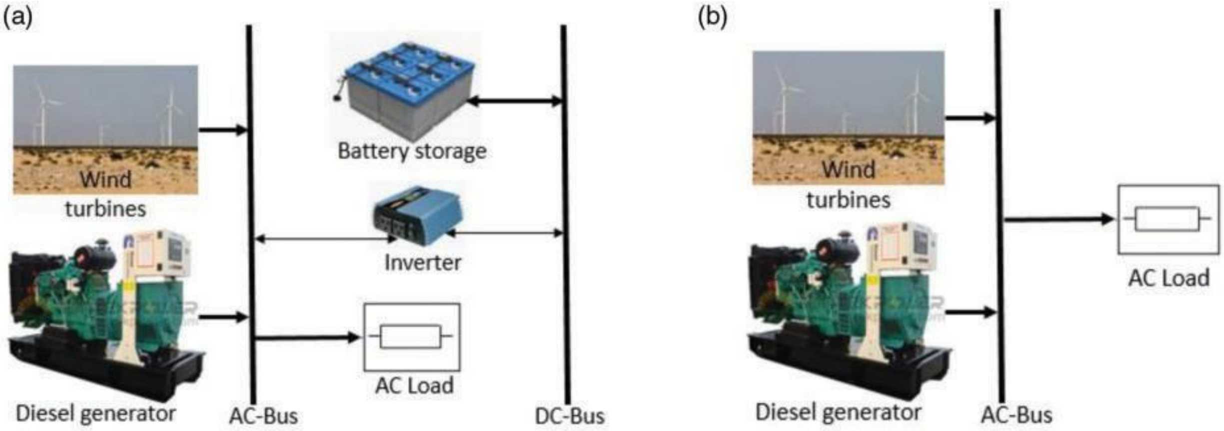


Figure 2-1 Wind-diesel hybrid power systems (a) with and (b) without battery backup [1]

2.1.2 Photovoltaic (PV)-diesel (PV-DSL) hybrid power systems with and without battery

A Photovoltaic-Diesel (PV-DSL) hybrid power system (HPS) consists of PV panels to convert sunlight into direct currect (DC), diesel generator/s, inverters to convert the DC output into alternating currect (AC), battery bank to store excess solar energy, AC and DC buses to distribute the power throughout the system, and smart control system to manage and ensure that the amount of hybrid energy matches the demand [1]. The following Figure 2-2 gives a simple representation of a typical PV-DSL hybrid power system.

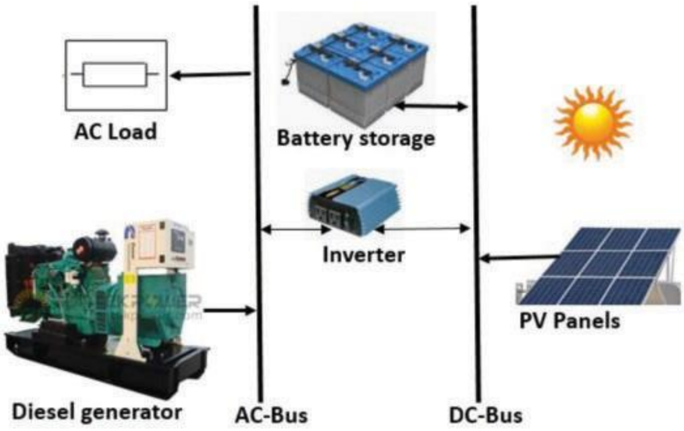


Figure 2-2 Solar PV-diesel with battery backup (PV-DSL-BAT) HPS [1]

2.1.3 *Wind-photovoltaic (WND-PV) hybrid power systems with and without battery*

Askari and Ameri (2012) conducted a comprehensive feasibility analysis of different HPS to supply electricity to a community with 50 households in Kerman, Iran in order to find the technically and economically best system based on the lowest Cost of Electricity (COE). the studied systems were: Photovoltaic (PV) with battery (PV-BAT), Wind turbine with battery (WND-BAT), and Wind-PV hybrid with battery (WND-PV-BAT).

Based on optimized results, PV-BAT was recommended for the rural community under consideration. The study identified an optimal HPS with a required 72 kW of PV capacity, 10 kW of wind turbine capacity, and a battery bank of 11 kWh. The analysis also showed the potential benefits of installing a hybrid WND-PV generation system at the site.

2.1.4 *Wind-photovoltaic-diesel (WND-PV-DSL) hybrid power systems with and without battery*

The simulation results showed that WND-PV-BAT HPS was the most suitable power system with for the location under consideration. The optimal system resulted in 81.7% reduction in overall cost compared to diesel only system and 100% reduction in GHG while satisfying 100% energy needs with 63.9% access energy.

2.1.5 *Grid (GRD) connected hybrid power systems*

A WND-PV-GRD grid connected HPS with 1000 kW of wind and 50 kWp of PV was proposed for grid-connected applications. A study suggested some guidelines on how to monitor the performance of such a system in the local environment of Spain. Caballero et al. (2013) presented an optimal HPS (WND-PV- GRD) small grid-connected system for a community with 15 households in Hanga Roa City in Easter Island and can result in reduction of 17,533 tons of GHG annually.

Figure 2-3 shows a microgrid connected HPS.

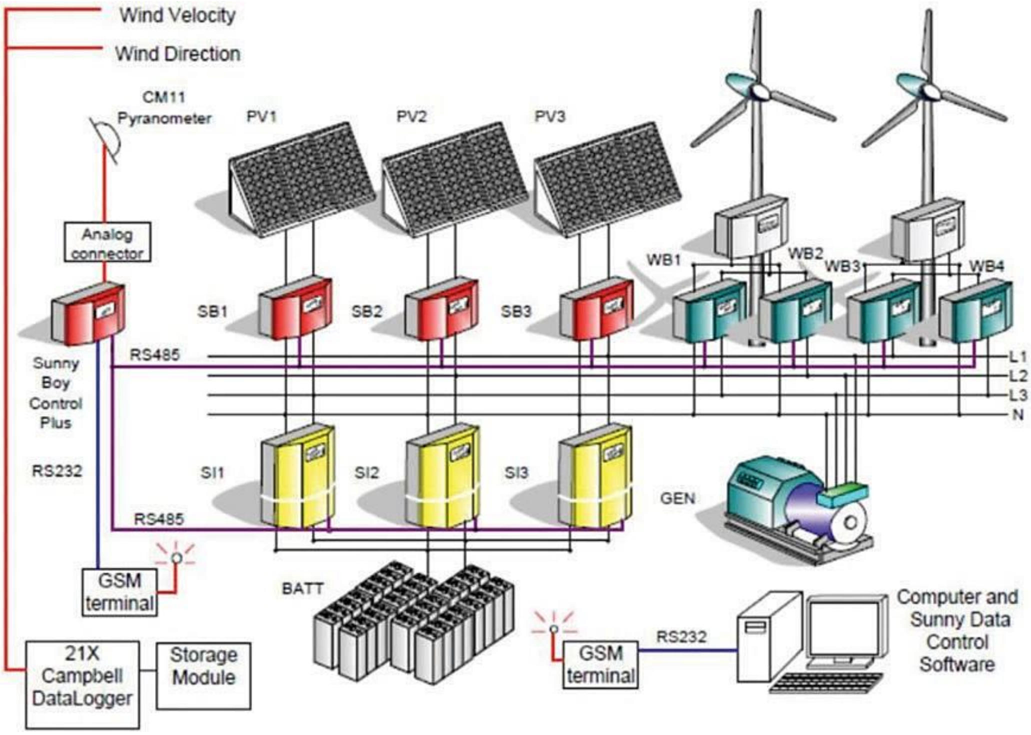


Figure 2-3 Schematic diagram of an optimized microgrid system [1]

A microgrid is an independent energy system that serves a specific local area, can use multiple sources of renewable energy, and is controlled by a software-based system. Microgrids are usually connected to traditional electric grids, but they can operate independently during an earthquake or other natural disasters.

Figure 2-4 shows the off-grid connection of sample HPS.

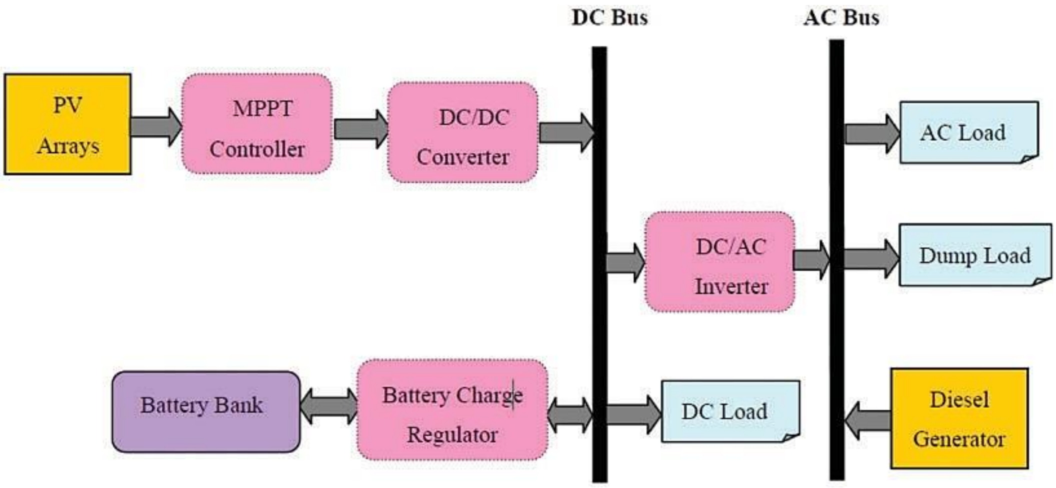


Figure 2-4 A simple block diagram of an off-grid PV-DSL-BAT HPS [1]

2.2 Control of the system

In order to use this system and get the best efficiency and full control, a control system is needed in order to manage the different sources to facilitate efficient coordination, and to arrange the operation of start-stop of the generator by employing intelligent algorithms and programs, minimizing fuel consumption and improving system stability. The control system is also used to manage the charging/discharging of the battery bank to ensure efficient energy storage and to maximize the battery lifespan [3].

Figure 2-5 shows the connection of the system with the control unit to perform the desired configuration.

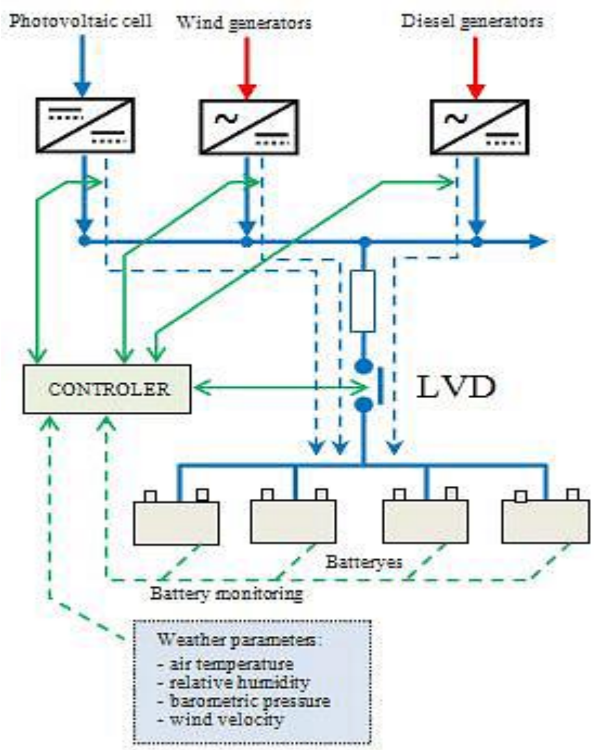


Figure 2-5 Control of hybrid system [3]

- **Control strategies**

The central component of the off-grid power management system is the Programmable Logic Controller (PLC) unit. The PLC unit acquires data from the connected sockets and PLC switches. The programming depends on using this input data and referring to stored memory to define control strategies. When grid power interruption happens, the PLC initiates a decision-making process to supply the load with needed power taking into consideration the status of batteries pack and the charging condition:

1) If the charge status of the battery is medium or high, the PLC sends a signal to the relay switch to provide the inverter with power to the load.

2) If the charge status of the battery is low or very low, then the PLC sends a signal to the generator change over (generator automatic start switches) so the generator will supply the load.

3) If grid power come back, the PLC unit turns off the generator and opens the relay switch of the battery, so the system will stop and the load is supplied from the grid.

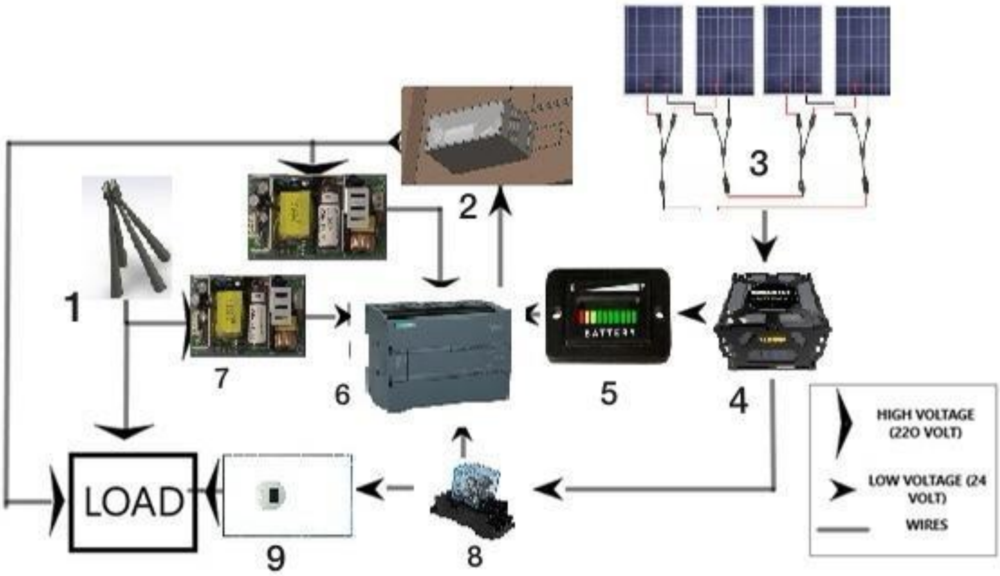


Figure 2-6 Detailed block diagram

The block diagram shown in Figure 2-6 details the components in order to understand the connection. This system implements a hierarchical control strategy for managing the power supply in the absence of grid connectivity. The Programmable Logic Controller (PLC) (6) serves as the central control unit, receiving information from the different components:

- First, the control system depends on the grid power (1) so the Power electronics (7) convert the 220 VAC to 24 VDC which provides the PLC (6) the operational status of grid.
- Second, if a grid (1) interruption happens, the Power electronics give a negative signal to the PLC (6), so the PLC unit decides which battery pack could supply the load. When it comes to the battery, the battery indicator (5) provides the PLC the current state of the battery pack (4). If the battery pack has sufficient capacity, the relay switch (8) closes, and the load is supplied after converting the battery power from 48 VDC to 220 VAC by the inverter (9).
- Finally, if the battery pack is in low status of charge, the PLC sends a positive signal to the generator changeover (2) so it automatically starts to supply the load. If the grid power is restored, the PLC cancels all the previous strategies, allowing the load to supply directly from the grid.

2.3 *Flow chart diagram*

Figure 2-7 below shows the flow chart that describes the control of system to simplify the processes.

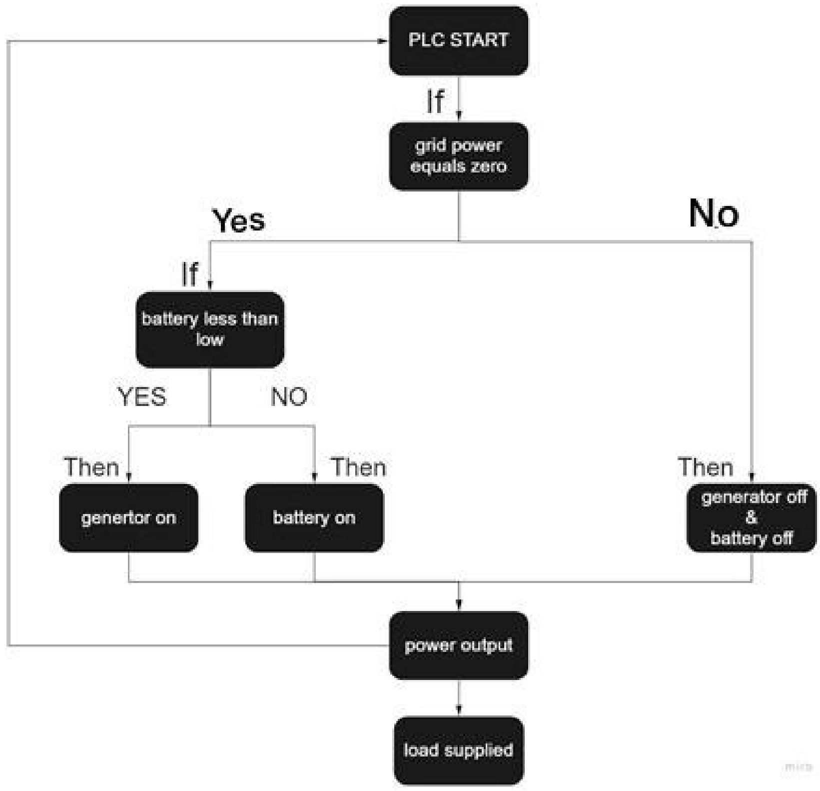


Figure 2-7 Flow chart diagram

CHAPTER 3 : RESEARCH METHODOLOGY

This chapter outlines the comprehensive methodology used in this research to design a hybrid power supply system for electricity generation. The approach has various stages, each explained in detail.

3.1 System Design Calculations

The following system parameters were calculated:

- ***Battery Capacity:*** to provide the system with sufficient energy storage capability in order to fulfill the power requirements during periods of limited or absent renewable energy generation.
- ***Evaluation of Photovoltaic (PV) System Energy Production:*** The daily energy production of the PV system was calculated, in order to determine the required size of the solar panel array necessary to fulfill the targeted energy demands.

These calculations consider various factors, such as the average daily sunlight duration at the designated location, anticipated load demands, and the desired autonomy of the system (i.e., the number of days the battery can sustain the load in the absence of solar or wind power).

3.2 System Design using CAD Software

Following the calculations, the SolidWorks CAD software was used to create a detailed design of the hybrid power system and its different components, using 3D modeling with dimensional specifications detailed in millimeters (mm). The used software provides several advantages to the project including clear visual representation of the complete system, with accurate dimensions, and documentation of the CAD models for reference.

3.3 Component Selection

According to the calculated parameters and the 3D system design, commercially available examples of the different components of the hybrid power system were selected, including:

- The solar panels with the specific dimensions and power production capacity
- The batteries with sufficient storage
- The generator considering fuel efficiency
- Control system: like controllers and transfer switches
- Wind turbine (optional)

The different components were selected considering specifications, compatibility, and cost. a prototype was also proposed using the selected elements.

3.4 Prototype Development

A prototype combining the suggested system components was proposed. calculations were made in order to reflect a full-scale system which were: the prototype total energy consumption, the expected power production of the chosen solar panels for the prototype, and the power required to charge the battery using the PV system.

3.5 Control Network Design

The system used a Programmable Logic Controller (PLC) to manage and operate different functions based on pre-defined programs. These programs include switching between power sources (solar, generator, battery), battery charge and discharge, and monitoring system input/output parameters. Therefore, a control network design was made as a PLC ladder diagram to ensure the efficient operation of the proposed prototype of the hybrid power system.

3.6 CAD Drawings and Belt Design

Using SolidWorks CAD software, a 3D model was designed for the suggested prototype and the belt drive system, using the calculated parameters, in order to make sure that the prototype is actually mechanically feasible and functional if implemented as a full-scale system.

3.7 Cost Analysis

A cost analysis of the prototype was also performed, which considered the essential system components and they are:

- The solar panels
- The batteries
- The generator,
- The control system components like the controller and the transfer switch,
- The wind turbine (if included),
- The wires, and labor costs of the installation.

This was done in order to evaluate the cost-effectiveness of the system and its sustainability. the investment return of the project was also calculated.

This methodology chapter details a comprehensive approach utilized in this research project. Each stage contributes to the development of a robust, cost-effective, and sustainable hybrid power system capable of meeting energy needs in various applications.

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 *SYSTEM DESIGN*

4.1.1 Calculation

In order to design the hybrid system, the size of the required battery capacity to supply the 2-kW load for a maximum of 5 hours is calculated, by using the formula Watt-hours (Wh) = Power (W) x Time (hours) as follows:

$$Battery\ Capacity\ (Wh) = 2\ kW \times 5\ hours = \mathbf{10\ kWh}$$

Therefore, the battery capacity would be at least 10 kW therefore to supply the devices with the power needed.

A. Battery calculation

Hybrid systems often utilize series-connected 12-volt or 48-volt batteries. the 48-volt type was preferred due to several advantages:

- Reduced Losses: Higher voltage systems experience lower transmission losses compared to lower voltage systems. This is because the current required to transmit the same amount of power is lower at higher voltages, which translates to less energy lost as heat in the cables.
- Reduced Cable Diameter: Using a higher voltage allows for cables with a smaller cross-sectional area to transmit the same power. This translates to cost savings on copper materials and potentially easier installation due to the smaller cable size.

➢ Assuming battery capacity 10 kWh to get the optimum design:

$$Battery\ Power\ capcaity = \mathbf{10\ kWh}$$

➢ The ampere supplied by the battery pack should be as follows:

$$Nominal\ ampere\ per\ hour = \frac{battery\ power\ capacity}{battery\ pack\ voltage} \quad (1)$$

$$= \frac{10\ kWh}{48\ Volts} = \mathbf{208.33\ ah}$$

➢ To obtain the ampere needed by the battery, the following formula is used (average charging hours = 5 hours)

$$Ampere = \frac{The\ nominal\ ampere\ per\ hour}{working\ hours} \quad (2)$$

$$= \frac{208.33ah}{5\ hours} = \mathbf{41.666\ A}$$

Therefore, the battery that was selected according to the results obtained (the calculated voltage and ampere) was the “vanguard” lithium-ion battery (Annex 1).

The battery pack specification is shown below in Table 6-1

Table 4-1 Commercial vangurd Battery pack sepcifications [4]

Configuration	**Lithium-Ion, 14S**
Nominal Voltage (V)	51.6 V
Top Voltage (V) per IEC 61960	58.8 V
Top Voltage (V) for EV-Applications	58.1 V
Cutoff Voltage	35
Capacity at Max Discharge (Ah) for EV-Applications	195Ah / 9.5kWh
Nominal Capacity per IEC 61960	197.4Ah / 10.17kWh
Communication Protocols	CAN J1939 (29-bit) Plus flexible secondary CAN interface
Discharge Temperature Range	-20˚C to 60˚C
Storage Temperature Range (1 Month / 1 Year)	-20˚C - 60˚C / -20˚C - +25˚C
Marketed Durability Hours/Cycles	Up to 2000 to 80% of initial capacity
Rated Charging Current (A)	50A
Rate Discharging Current (A)	100A
Parallel Capable	Yes, up to 10 batteries
Standard Charge Time	< 12 Hours
Vanguard Charger Input Power	<12A, 120V, 60Hz / 220V, 50Hz
Vanguard Charger Output Power (W)	1050W, 20A

B. Solar panel calculation

The battery capacity required equals 10 KWH, so in order to get the battery charged once per day, the energy supplied by PV's must equal 2 KWH minimum. So, calculations are done to get the number of solar cells and panels in order to design the electrical system to provide the power needed:

- To calculate the power required to charge the battery system, the voltage and charge current of battery are needed to do the calculations.

$$Voltage\ of\ battery = \mathbf{51.6\ V}$$

- The battery average voltage from the data sheet above is approximate to 52 volts.

- The charging current of the battery is up to 50 A maximum. But to get the amperes needed by the battery, the following formula is used (average charging hours = 5 hours):

$$Ampere = \frac{The\ nominal\ ampere\ per\ hour}{working\ hours} \tag{3}$$

$$= \frac{208.33ah}{5\ hours} = \mathbf{41.666\ A}$$

- By multiplying the nominal voltage by the charging current needed to supply the battery:

$$\begin{aligned} P &= V_n \times I_{charging} \\ &= 48 \times 41.66 \\ &= \mathbf{1999.68\ W} \end{aligned} \tag{4}$$

- Charging the battery with a power input of 1999.68 watts (W) for a minimum duration of 5 hours is sufficient to achieve full charge:

$$1999.68\ watt \times 5\ hours = \mathbf{9998.4\ W / day}$$

Therefore, the minimum wattage to supply by the solar panels should be 9998.4 watts per day (5 hours or more to get charged). The 5 hours is the average charge time in a year when the solar panels are in the best situation.

Cell selection

- To design the solar panel, the number of cells required is calculated using the following formula (one cell power production according to the data-sheet in Annex 2 = **4.8 W**):

$$The\ number\ of\ cells = \frac{the\ power\ output}{power\ of\ cell} \quad (5)$$

$$= \frac{1999.68\ watt}{4.8\ watt} = \mathbf{416.6\ solar\ cells\ minimum}$$

- For the best design, cells be must distributed in the panels equally and in uniform rows and columns. All panels must be identical. Therefore, there would be 11 rows and 10 columns of cells for each solar panel and 4 solar panels to obtain the minimum 417 solar cells.

$$Number\ of\ cells\ per\ panel = 10 \times 11 = \mathbf{110\ cells\ per\ solar\ panel}$$

$$=> 110\ cells\ per\ solar\ panel \times 4\ panels = \mathbf{440\ solar\ cells}$$

- Considering the 440 solar cells, which is the best design, the power supplied by the cells is calculated:

$$Power\ output\ of\ cells = number\ of\ cells \times power\ output\ for\ each\ cell \quad (6)$$

$$= 440 \times 4.8 = \mathbf{2112\ W}$$

- Dividing the power output of cells by the number of panels:

$$\frac{2112}{4} = \mathbf{528\ W\ per\ panel}$$

Thus, under optimal conditions, the maximum power output of the solar system is **2112 watts per hour** (Wh). This generated energy is then used to charge the battery pack.

4.1.2 *Drawings*

The design of the hybrid power supply system assembly and its individual components was accomplished using SolidWorks CAD software. All dimensional specifications are provided in millimeters (mm) for clarity and consistency.

A. Overview

An overview of the hybrid power system installed on the roof top of a building is presented in the following figure (Figure 4-1).

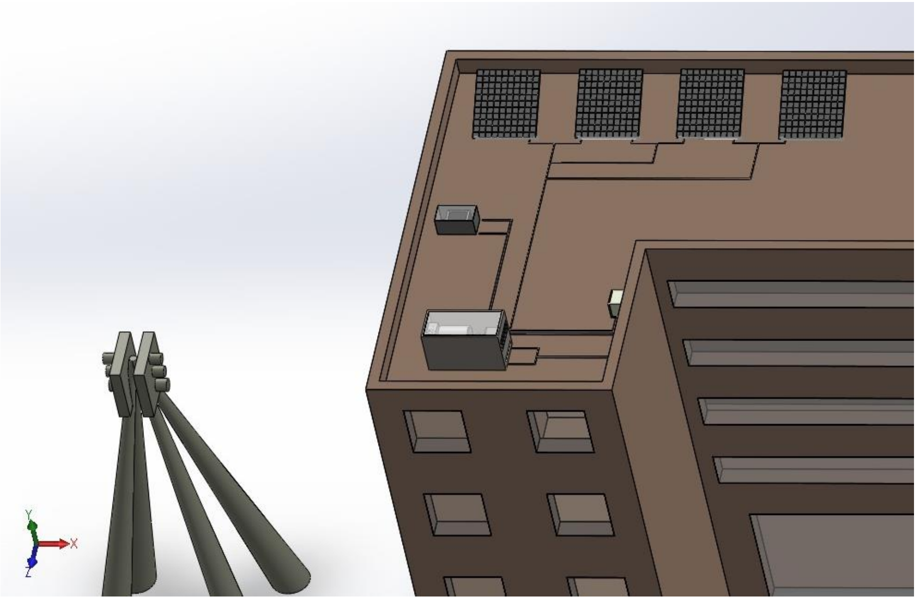


Figure 4-1 Overview of hybrid power supply system (*SolidWorks CAD*)

B. Battery pack

Figure 4-2 below illustrates A detailed drawing of the battery pack, including all dimensions. Figure 4-3 gives an overview of the battery pack with its protective case.

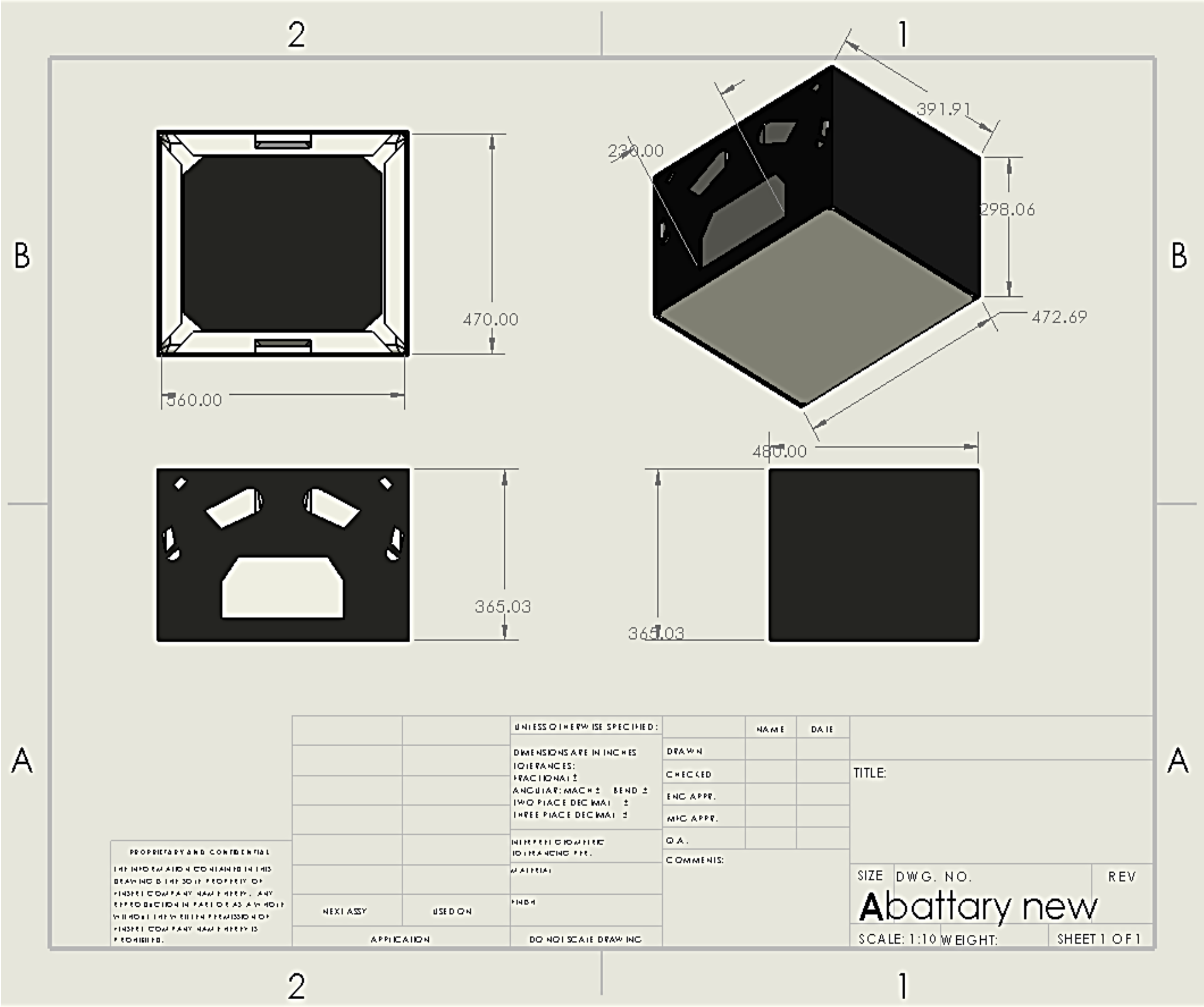


Figure 4-2 Drawing of the battery pack (mm) (*SolidWorks CAD*)

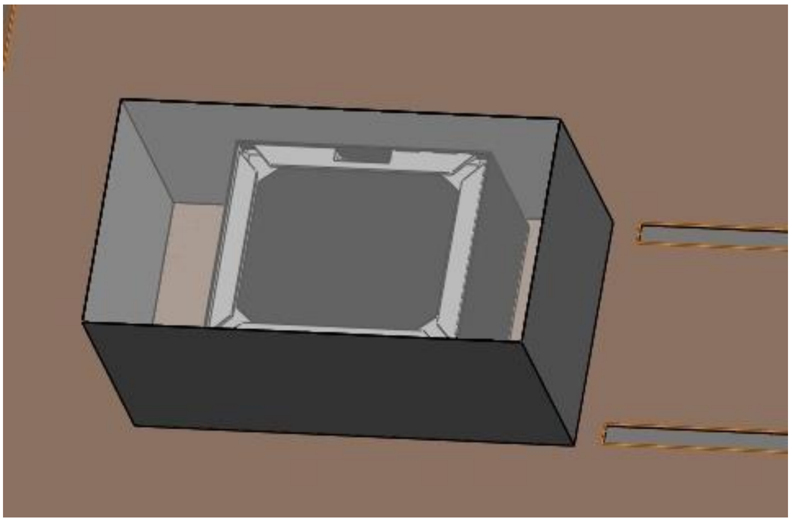


Figure 4-3 Battery pack overview with protection housing (*SolidWorks CAD*)

C. Generator

Figure 4-4 below shows a detailed drawing of the generator including all dimensions (mm), and figure 4-5 shows an overview of the generator with the protection case.

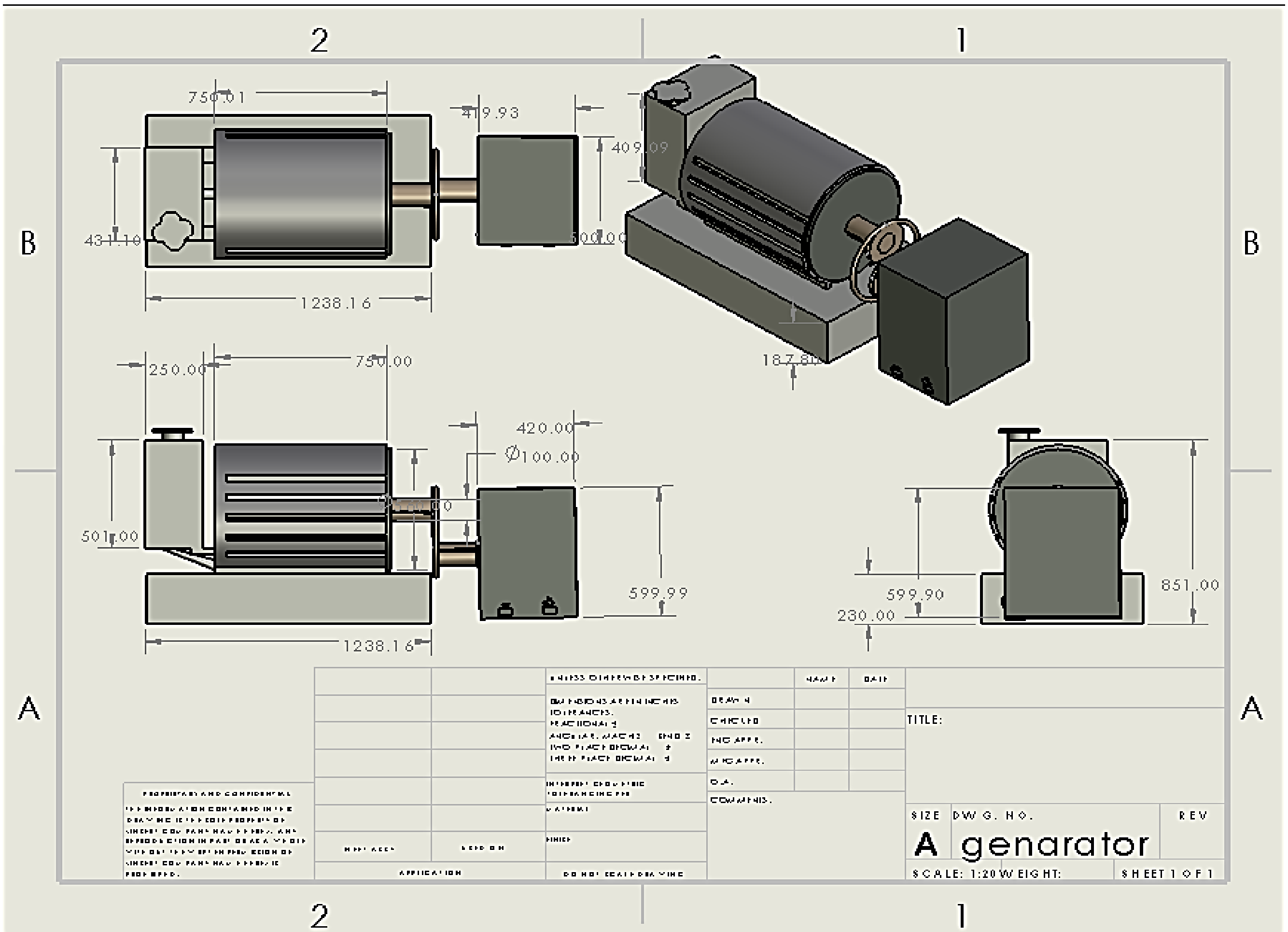


Figure 4-4 Drawing of the generator with dimensions (mm) (*SolidWorks CAD*)

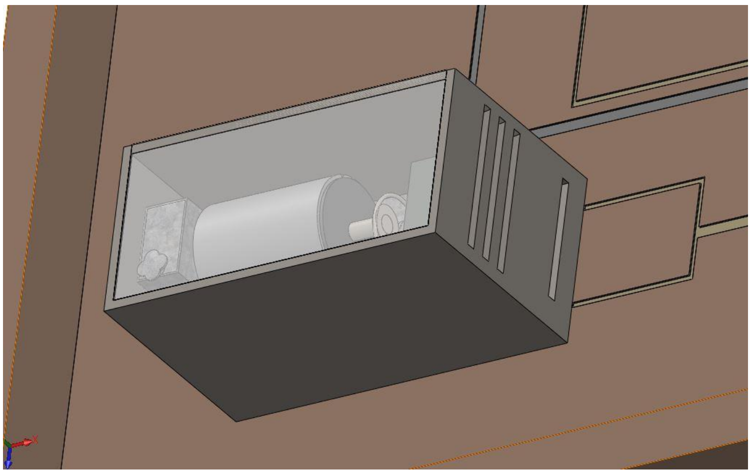


Figure 4-5 Overview of generator with protection housing (*SolidWorks CAD*)

D. Solar panels

Figure 4-6 and 4-7 below illustrate the solar cell drawing and overview:

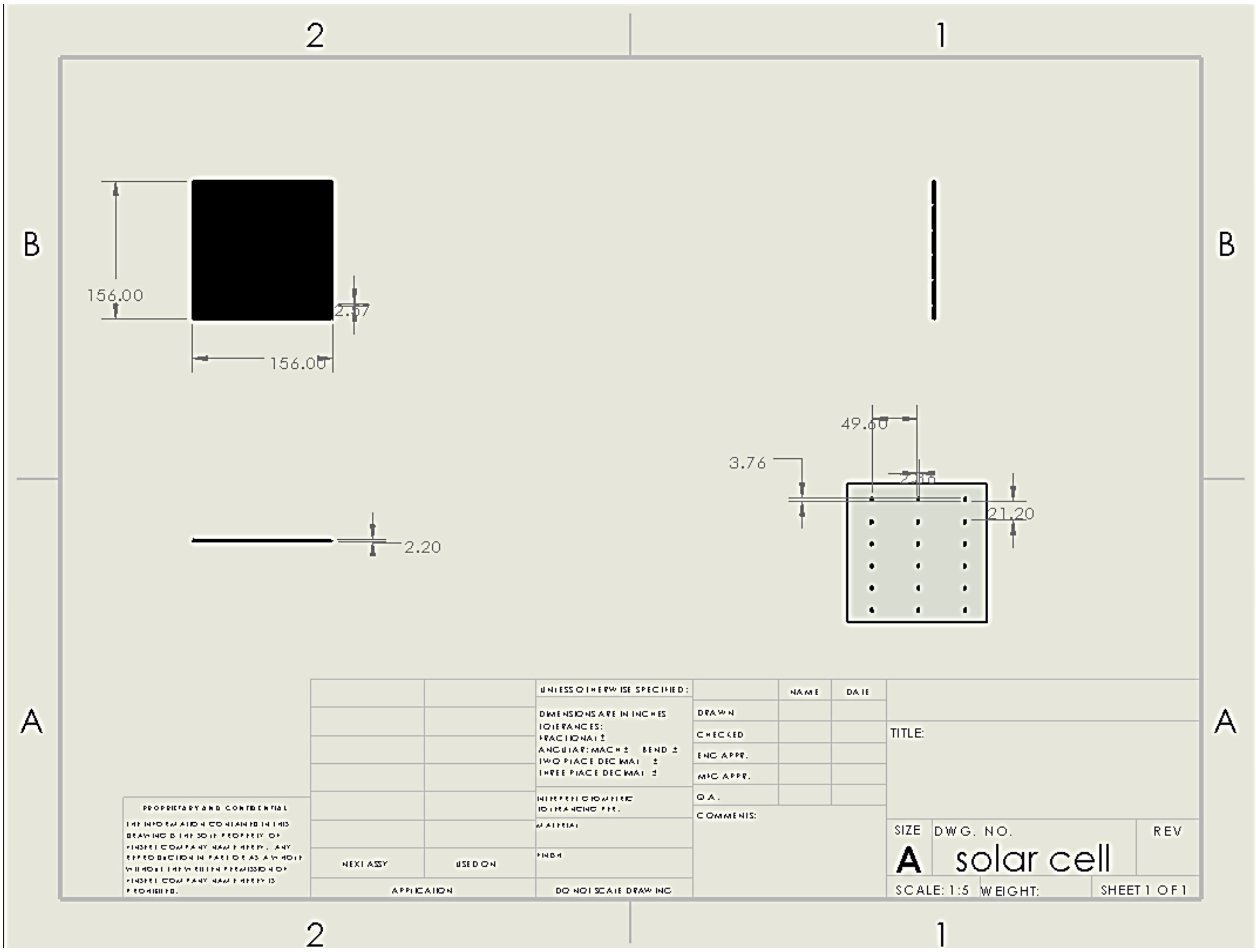


Figure 4-6 Drawing of a solar cell with dimensions (mm) (*SolidWorks CAD*)

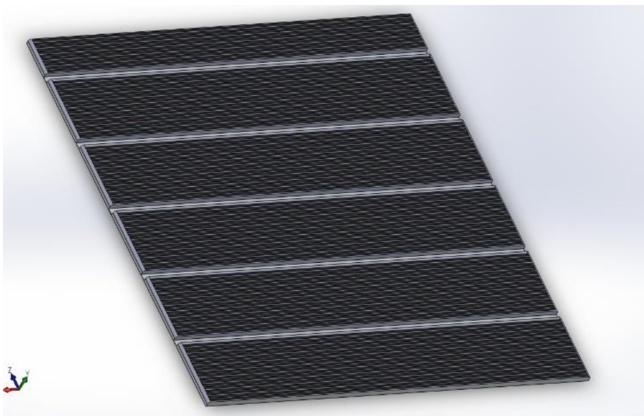


Figure 4-7 Overview of solar cell (*SolidWorks CAD*)

Figure 4-8 below gives an overview of solar panels on top of the building.

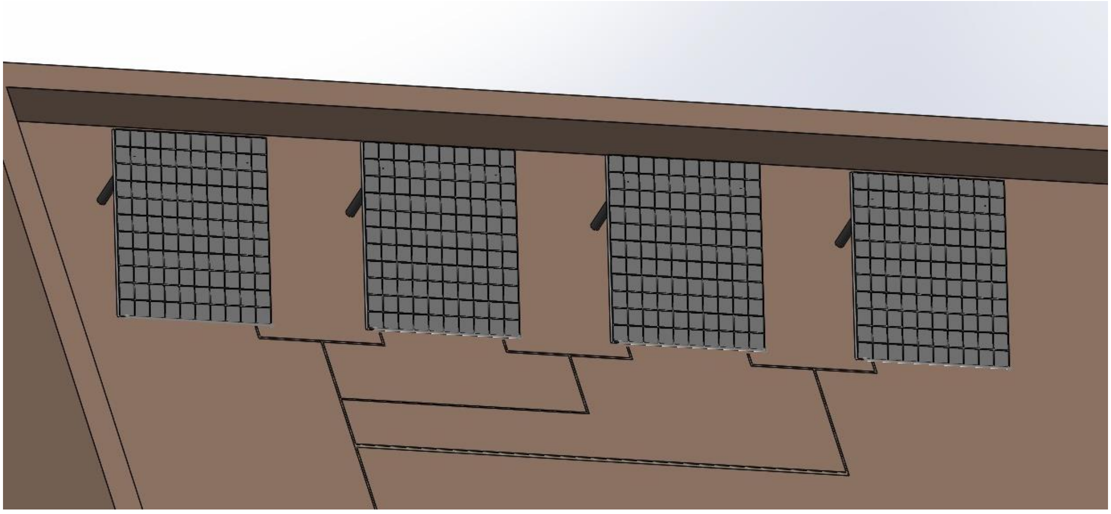


Figure 4-8 Overview of the four solar panel on top of the building (*SolidWorks CAD*)

Figure 4-9 below shows the detailed drawing of solar panels with dimensions in millimeter.

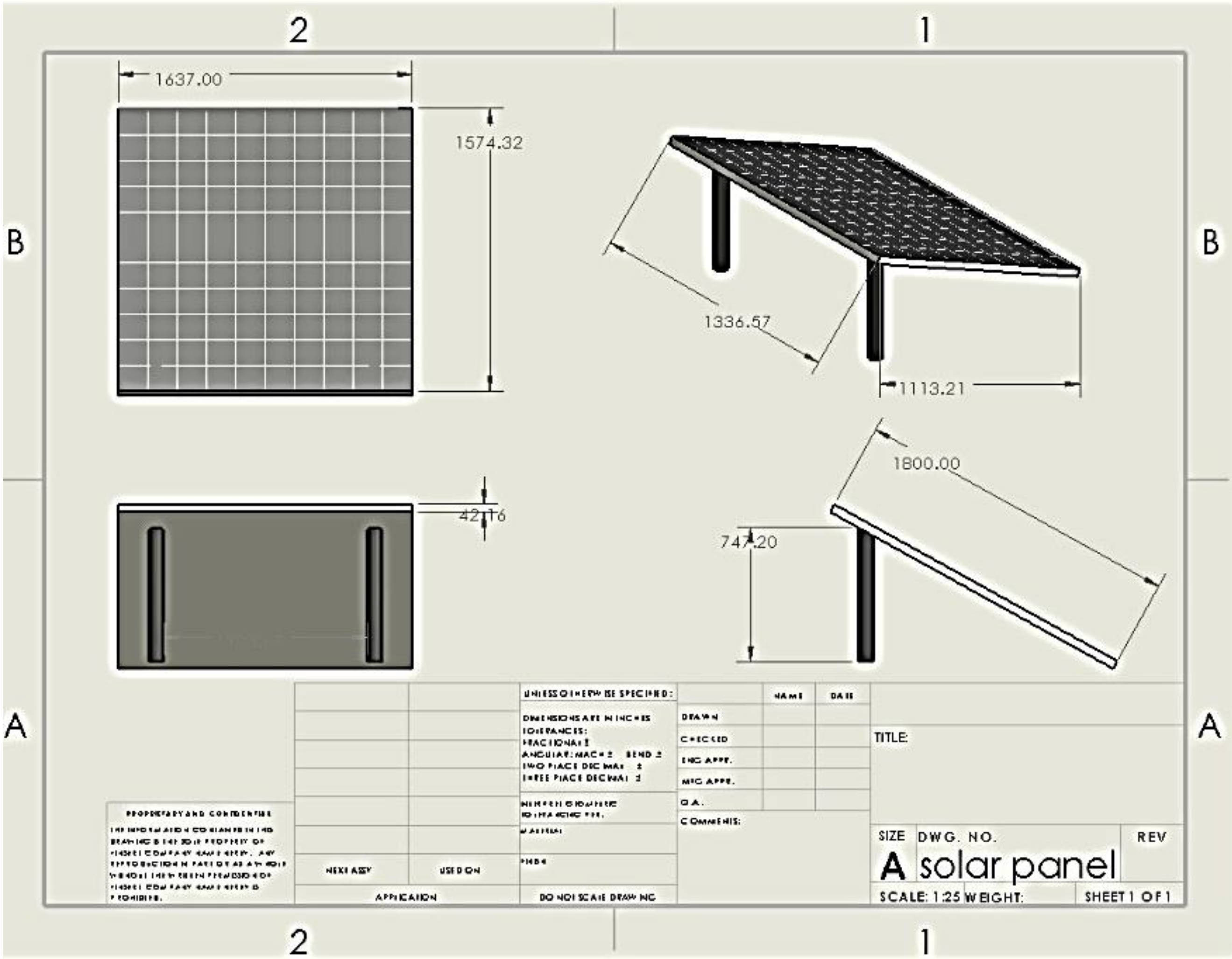


Figure 4-9 Solar panel drawing with dimensions (mm) (*SolidWorks CAD*)

Solar panels with textured surfaces are the typical type to be used in many applications. The surface is actually made from a 3.2 mm thick crystalline silicon which helps attract and trap light easily, even from non-direct angles of sunlight. That is by scattering the light and directing them to the solar cells, which ultimately leads to improved energy conversion efficiency [5].

E. Transfer switch

Figure 4-10 below shows the change-over which manages the generator's operation and might be integrated within the generator itself.

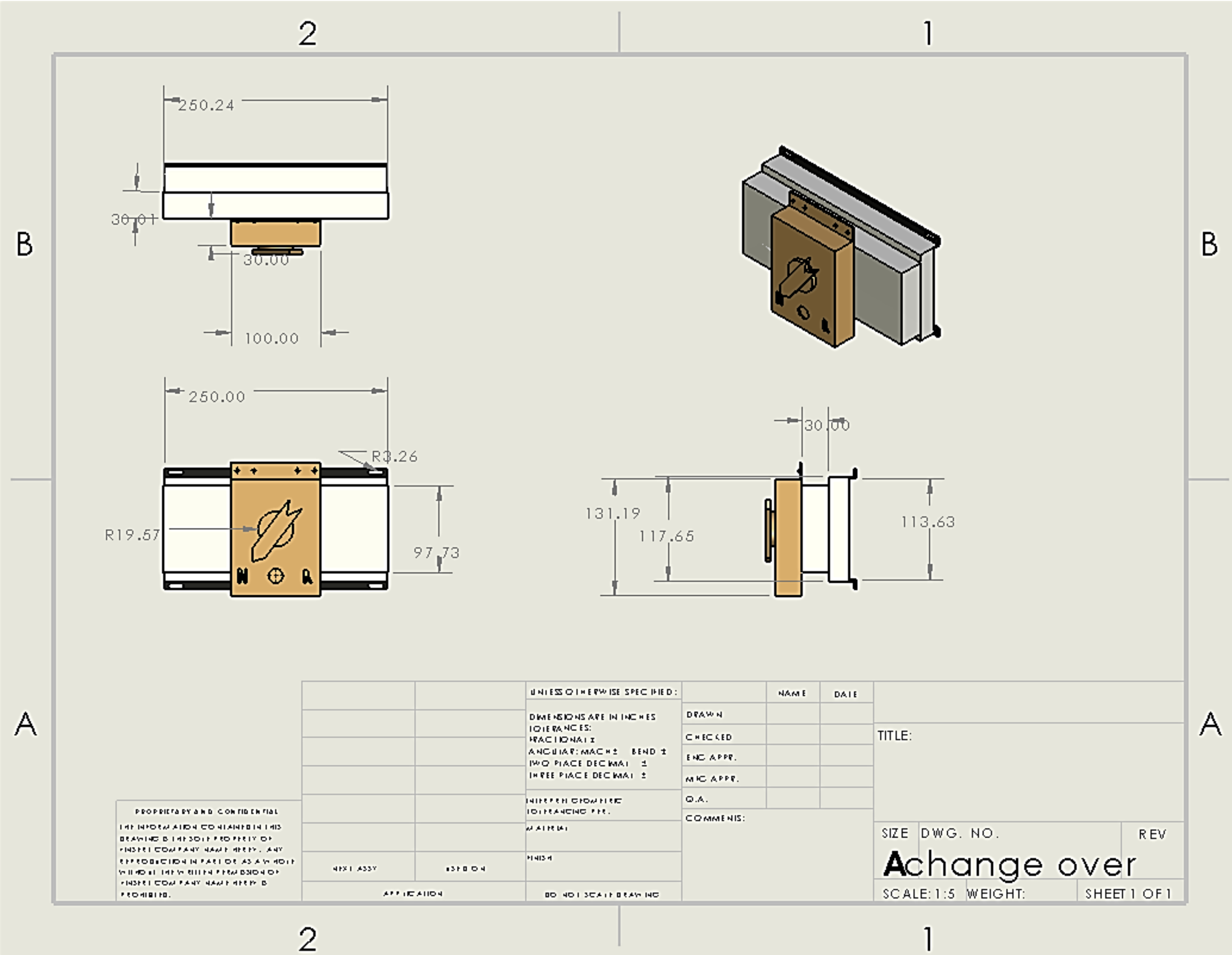


Figure 4-10 Transfer switch (change over) drawing with dimensions (mm) (*SolidWorks CAD*)

F. Programmable logic controller

Figure 4-11 shows the drawing of the Programmable logic controller unit with all dimensions in millimeter:

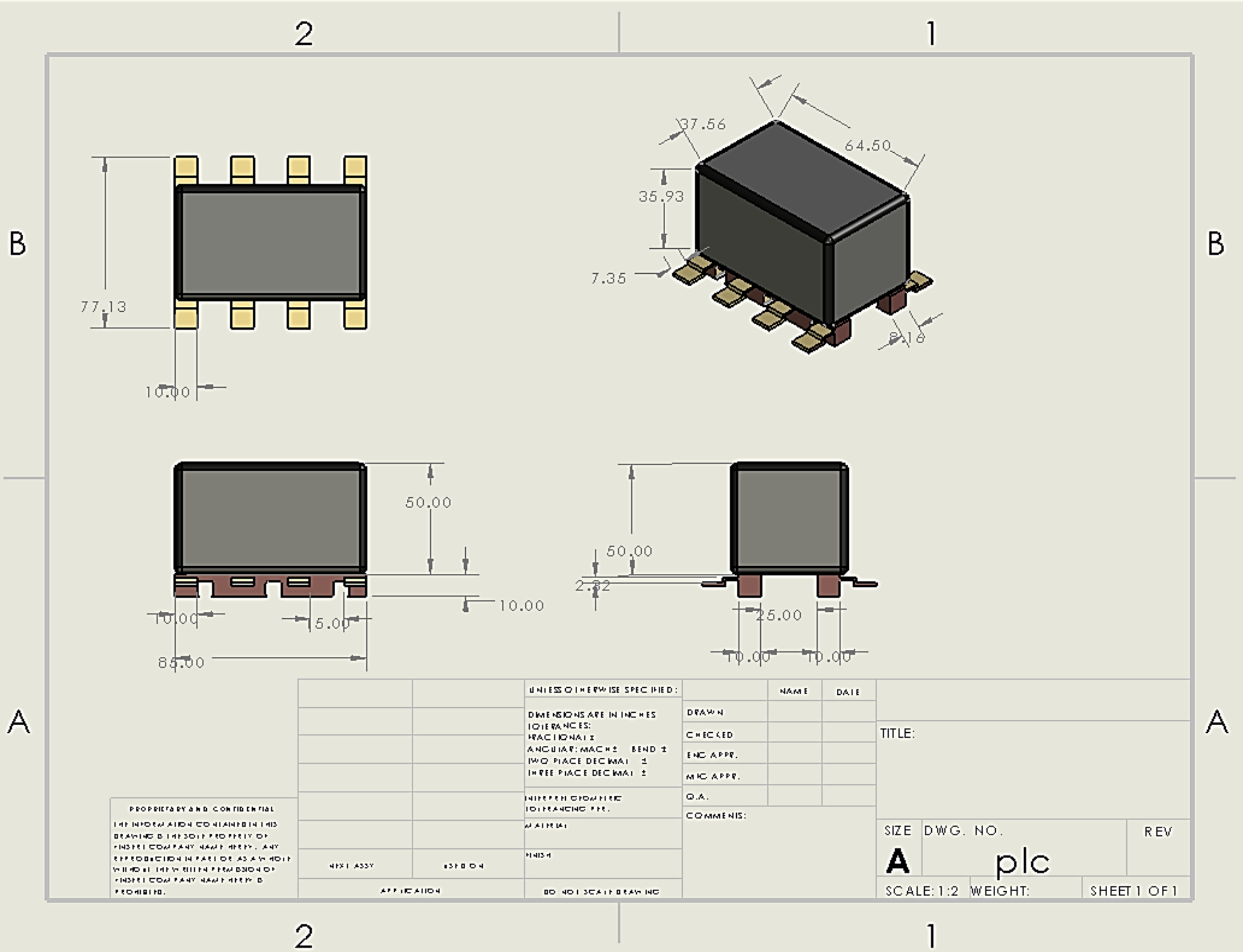


Figure 4-11 Drawing of Programmable logic controller with dimensions (mm) (*SolidWorks CAD*)

G. Power electronics

Figure 4-12 shows the drawing of Power electronics:

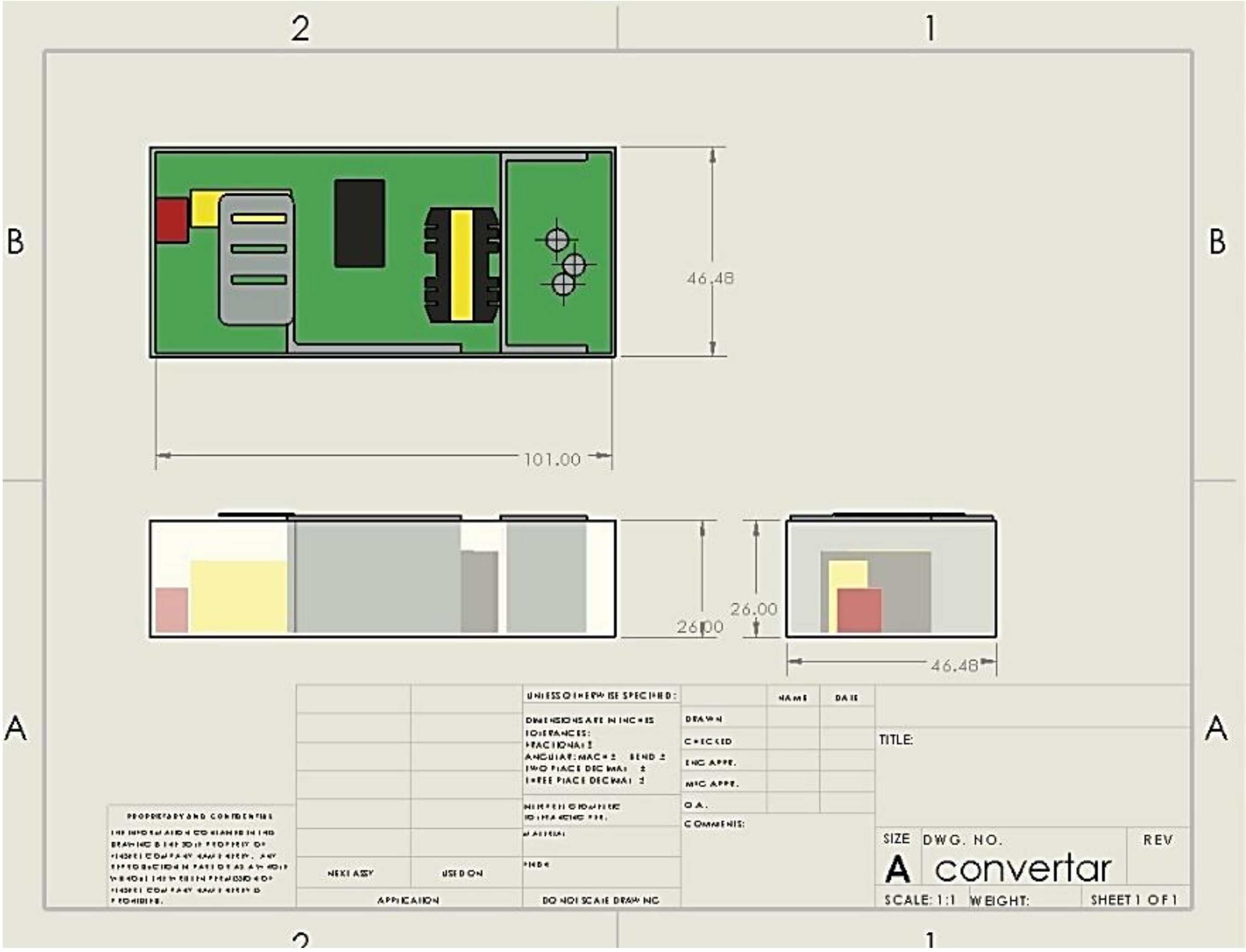


Figure 4-12 Drawing of Power electronics (*SolidWorks CAD*)

Figure 4-13 shows an overview of the Power electronics.

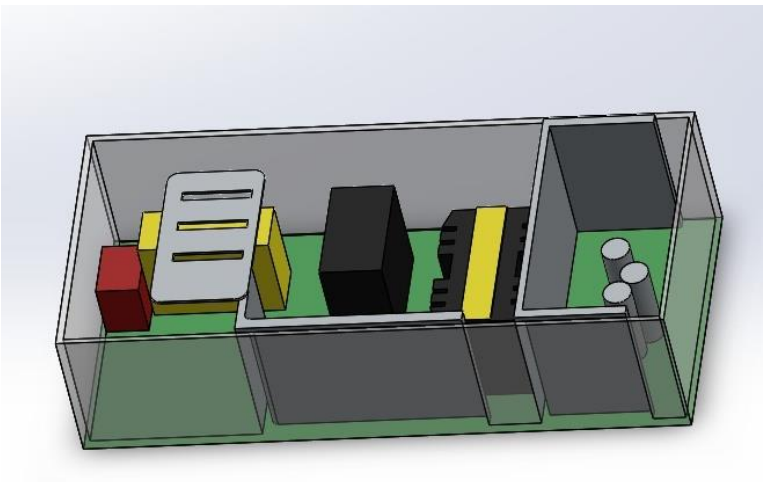


Figure 4-13 Overview of the Power electronics (*SolidWorks CAD*)

H. PLC system and control components housing drawing

Figure 4-14 shows a detailed drawing of the PLC and control components inside the protection housing in order to get the connection and cable management and to obtain easy maintenance.

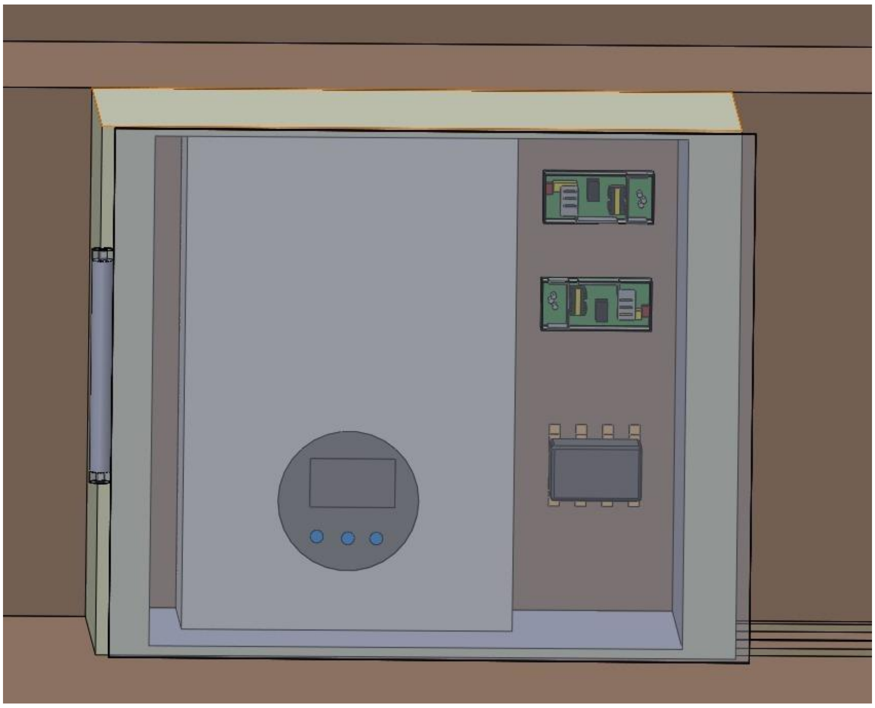


Figure 4-14 PLC system and control components housing drawing (*SolidWorks CAD*)

I. Electric power grid

Figure 4-15 shows the drawing of electrical power grid

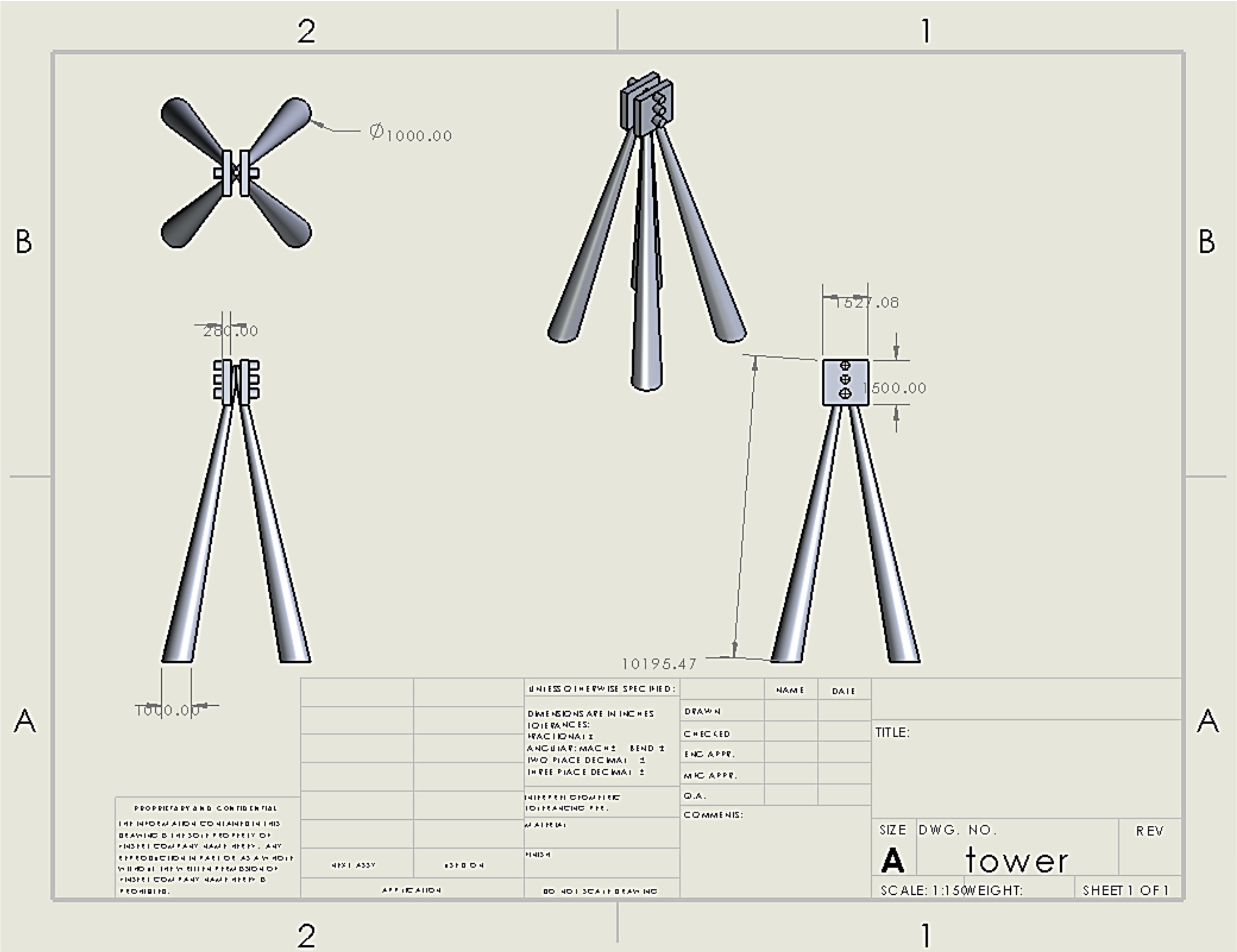


Figure 4-15 Electrical power grid drawing (*SolidWorks CAD*)

4.1.3 Control of system

The system employs a PLC as its central control unit, responsible for several key functionalities (environmental monitoring, battery management and operation, automatic system startup).

A. PLC system

The PLC receives information from connected sensors or input devices, processes the data, and triggers outputs based on pre-programmed parameters.

Figure 4-16 shows the PLC system, specifically illustrating the input data flow to the logic board. This data includes various parameters, and the system determines the corresponding outputs based on pre-programmed logic.

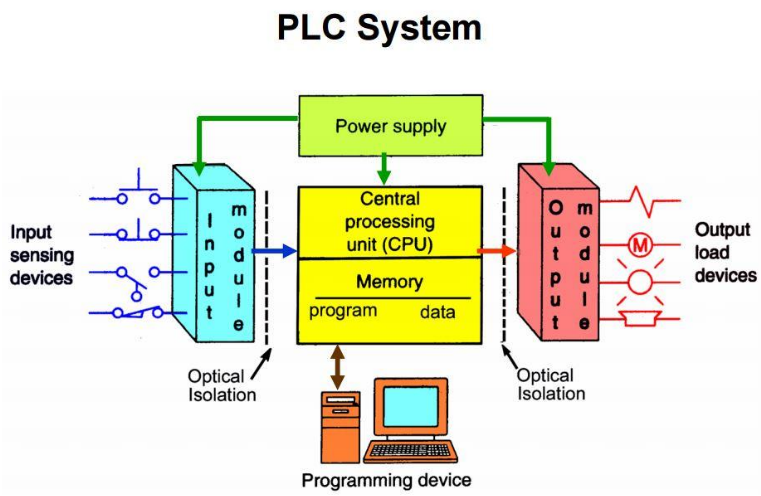


Figure 4-16 PLC system components [2]

B. System inputs

To use the PLC controller, sensors are needed which can be placed strategically to achieve the optimum operation of the system. Every sensor's purpose is to detect changes in the environment and send the information to the PLC for process, in order to make informed decisions and control the other system components accordingly.

C. Project sensors, components and switches

For successful implementation of a PLC-controlled system, Sensors, components, and switches must be chosen to install with the PLC system to achieve the control desired. There are the components for the system:

- ***Battery level indicator:*** To indicate the charge density of batteries, the situation of batteries, and the amount of power stored. Also, it gives the control unit the situation of batteries to decide the condition of the system.
- ***PLC unit:*** Used to control all components, take data from devices, and decide the system outputs.

➢ ***Selection of PLC***

The chosen PLC for system operation is the Siemens CPU 1214C - 6ES7214-1AG40-0XB0, which is shown in Figure 4-17 below.

Figure 4-17 Siemens CPU 1214C PLC unit [5]

Specifications [5]

- SIMATIC S7-1200
- CPU 1214C
- Compact CPU
- DC/DC/DC
- PROFINET port
- Onboard I/O: 14 digital inputs 24 V DC; 10 digital outputs 24 V DC; 0.5 A; 2 analogue inputs 0-10 V
- Power supply: 20.4-28.8 V DC
- Program/data memory 100 kB

1) Relays

Relays (Figure 4-18) manage the connection between batteries and the load (devices requiring power). The PLC implements pre-programmed control strategies to activate/deactivate the relays, thereby connecting or disconnecting the batteries from the load as necessary.

Figure 4-18 Relay switch

2) **Power supply Power electronics (220v to 24 volts convertor)**

The system necessitates power electronics in the form of a voltage converter to ensure compatibility with the PLC unit. This converter main tasks are:

- High voltage conversion: High voltage lines deliver power at a significantly higher voltage than the 12/24 volts DC supported by the chosen PLC unit.
- Enabling PLC operation: The voltage converter transforms the high voltage from the lines to a low voltage level compatible with the PLC's operational range.

➢ ***Selection of Voltage converter***

The chosen Voltage converter is the Condor power supply 24 Volt ,2.7A [6].

Figure 4-19 Power electronics 24 Volt Power Supply 2.7A, Switching [6]

3) Inverter

The inverter is used to convert the battery peak voltage from 48 Volt to 220 Volt so the load could work properly. Most loads work by 220 Volt 50 Hz power supply.

The selected inverter is the BST-INV-BG-3KW from Entelechy company solar inverter wall-mounted with rated power 3 KW and peak power up to 9 KW, built in with intelligent control chipset and a continuous and stable sine wave output [7]. Figure 4-20 below shows the shape of inverter.

Figure 4-20 Wall-mounted Inverter (3KW) [7]

Specifications [7]

- Model: BST-INV-BG-3KW
- Rated power: 3 KW
- Peak Power(220ms): 9 KW
- Standard battery voltage: 24/48 VDC
- Operating temperature: -10- 40 C
- Net weight: 22.6 KG

➢ ***<u>Dimensions</u>***

H: 510 mm, W: 320 mm, T: 140 mm

4.2 PROTOTYPE IMPLEMANTION AND CALCULATION

In order to show the working principle of the project, a small prototype project is done. The small project works the same way as the main project principal work. the main idea of the project is to supply a load when power interruption happens. The hybrid power system (HPS) simple components and structure will be explained also.

4.2.1 Prototype components

A. SITOP PUS 100S

Figure 4-21 SITOP PUS 100S [8]

- Technical data SITOP PUS 100S [8]

  The SITOP PSU100S, a powerful, regulated standard power supply for automated equipment and systems, is part of the SITOP smart product line (see Annex 3 for more info of the different products). These low-profile power supply units provide exceptional overload behavior in addition to high efficiency [8].

- The benefits of SITOP PSU100S include [8]:
  - Wide-range input, which allows them to be connected to almost any 1-phase line supply around the world
  - Output voltage can be adjusted in the range 22.2 (24) ...28 V or 11.5…15.5 V
  - Brief overload capability of 150% for 5 s/min (extra power)
  - Continuous overload capability of 120% up to an ambient temperature of +45°C
  - Integrated signaling contact for "24 V OK" or "12 V OK"

- Ambient temperature -25 (0) ...+70 °C
- To increase the system availability, these reliable power supplies can be expanded using SITOP supplementary modules (redundancy module, selectivity module, buffer module), as well as SITOP DC-UPS modules.

B. PLC siemens s7-1200

Figure 4-22 PLC siemens s7-1200 [9]

Attached technical specification in Annex 4 [10].

- Wiring diagram [11]:

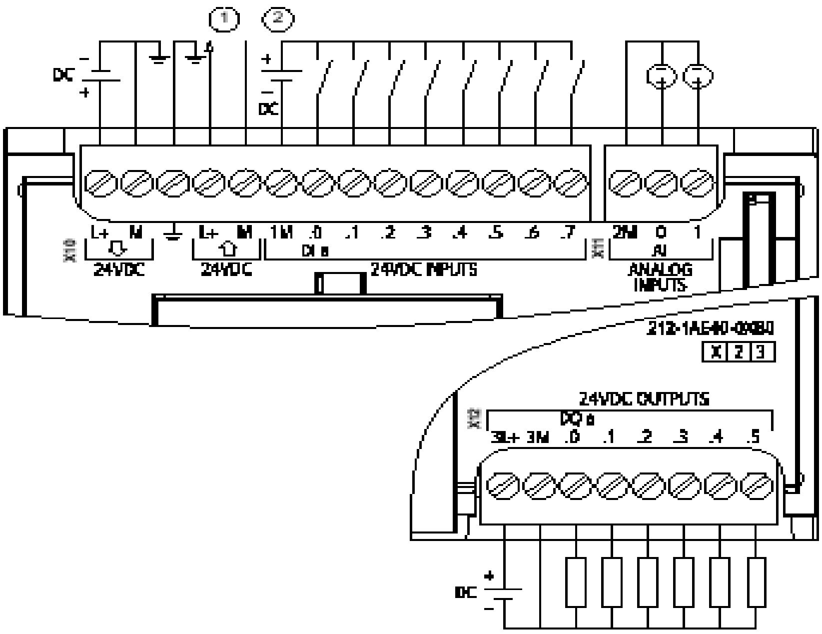


Figure 4-23 Wiring diagram PLC siemens s7-1200

Table 4-2 Connector pin locations for CPU 1212C DC/DC/DC (6ES7 212-1AE40-0XB0) [11]

①	- 24 VDC Sensor Power Out - For additional noise immunity, connect "M" to chassis ground even if not using sensor supply
②	- 24 VDC Sensor Power Out - For additional noise immunity, connect "M" to chassis ground even if not using sensor supply. - For sinking inputs, connect "-" to "M" (shown). - For sourcing inputs, connect "+" to "M". Note: X11 connectors must be gold. See Annex 4, Spare Parts for order number

C. 700-HA General-purpose Relay

Figure 4-24 General-purpose Relay [12]

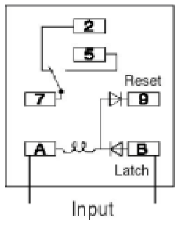
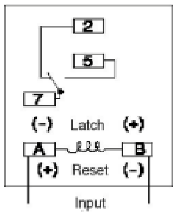
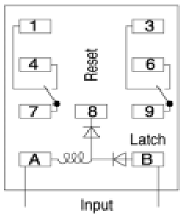
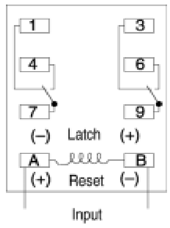
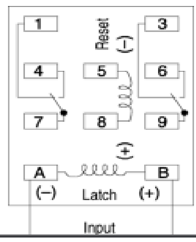
Photo	Description	Contact Rating	Wiring Diagrams AC[2]	Wiring Diagrams DC[3]	Coil Voltage	Cat. No.
	SPDT 1-Pole 1 Form C AgCdO Contacts (Single Coil AC or DC)	10 A			24V AC	700-HJ36A24
					120V AC	700-HJ36A1
					24V DC	700-HJ36Z24
	Sockets		700-HN153	700-HN154		
	DPDT 2-Pole 2 Form C AgCdO Contacts (Single Coil AC or DC)	10 A			24V AC	700-HJ32A24
					120V AC	700-HJ32A1
					240V AC	700-HJ32A2
					12V DC	700-HJ32Z12
	Sockets		700-HN153	700-HN154	24V DC	700-HJ32Z24
	DPDT 2-Pole 2 Form C AgCdO Contacts (Dual Coil[1])	10 A	DC Only		24V DC	700-HJD32Z24

Figure 4-25 General-purpose Relay specification [12]

An electromechanical relay is an electrical device used to distribute power on the basis of an order issued by the control unit. A relay opens and closes an electrical power circuit on the basis of logical information. American scientist Joseph Henry is credited with creating it. Relays have developed significantly since their creation, and they are used in many applications. Historically, they have been used to transmit signals like Morse code [13].

D. Battery

Figure 4-26 Expert power 12-volt battery [14]

Table 4-3 Expert power 12-volt battery specification [14]

Manufactor	ExpertPower
Brand	Expert Power
Model	EXP1290
Item weight	5.19 POUNDS
Product diminsions	5.99 · 2.53 · 3.69 inches
Item model number	EXP1290
Amperage	9 Amps
Voltage	12 Volts

The sealed lead acid batteries have a non-spillable construction and require no maintenance. They work in any direction and are perfect for both cycle and standby use. They have a life expectancy of three to five years when utilized in standby and are used for a number of purposes such as [15]:

- Emergency lighting
- Security alarms
- Fire alarms Home & Garden
- Consumer electronics
- Medical equipment

E. Arduino UNO R3

Figure 4-27 Arduino UNO R3 [16]

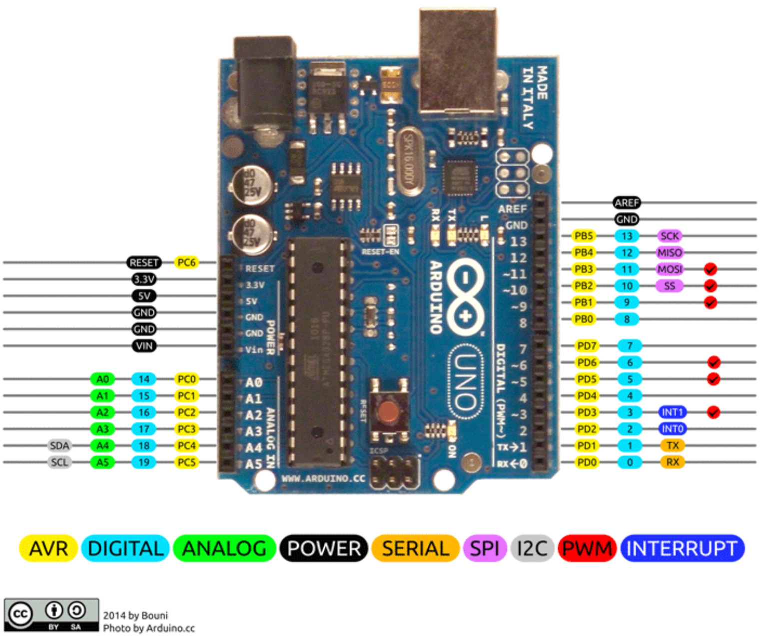


Figure 4-28 Arduino UNO PINOUT [16]

Figure 4-28 shows the pinout of Arduino UNO which is used to state the voltage sensor and gives signal to PLC (Arduino Uno Technical Specifications table in Annex 5 [16]).

- **Arduino Board [16]**

Through Arduino programming, we use the 14-digital input/output pins, by using the pinMode, `digitalRead` and `digitalWrite` functions. These pins work at **5V**, which can produce up to **40mA** and receive it also. they have internal pull-up resistor of **20-50 KOhms** that can automatically disconnect. Some of the pins used have the following functions: [16]:

Table 4-4: The function of the Arduino Board digital input/output pins [16]

Digital pin	Function
Serial Pins 0 (Rx) and 1 (Tx)	Reception and transmission of TTL data Connection to the compatible ATmega328P USB to TTL serial chip
External Interrupt Pins 2 and 3	Signal disruption in case of: Low value Changing value Rising of falling value
PWM Pins 3, 5, 6, 9, 11	Production of 8-bit PWM Using the function `analogWrite`
SPI Pins 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK)	SPI communication
Pin 13 (In-built LED)	Starting/stopping the built-in LED If PIN 13 High ➔ LED On If Pin 13 Low ➔ LED Off

6 other analog input pins are also used in this project. They produce 1024 different values by giving 10 bits of resolution. Their measuring range is from 0 - 5V, that can be augmented through the use of the AREF pin with `analogReference` function [16]. An example of the analog pin is presented in Table 4-5, along with 2 other Arduino Uno pins.

Table 4-5: The function of an analog pin with other Arduino Uno pins [16]

Pin	Function
Analog pin 4 (SDA) and pin 5 (SCA)	TWI communication (Wire Library)
Arduino Uno AREF	Using the function `analogReference` Provides reference voltage for the obtained analog inputs
Arduino Uno Reset Pin	If Low ➔ Microcontroller Reset

F. Electrical motor

Figure 4-29 1400 RPM speed electrical motor

The motor needed has a speed equal to 1400 revolutions per minute in order to reach the cat-off of the alternator to produce an electric current and a voltage of approximately 12 volts, which represents the actual generator (Technical data for motor attached in Annex 7 [17]).

G. Alternator

Figure 4-30 Bosch® -Alternator [18]

- Specifications of the alternator attached in Annex 8 [18]

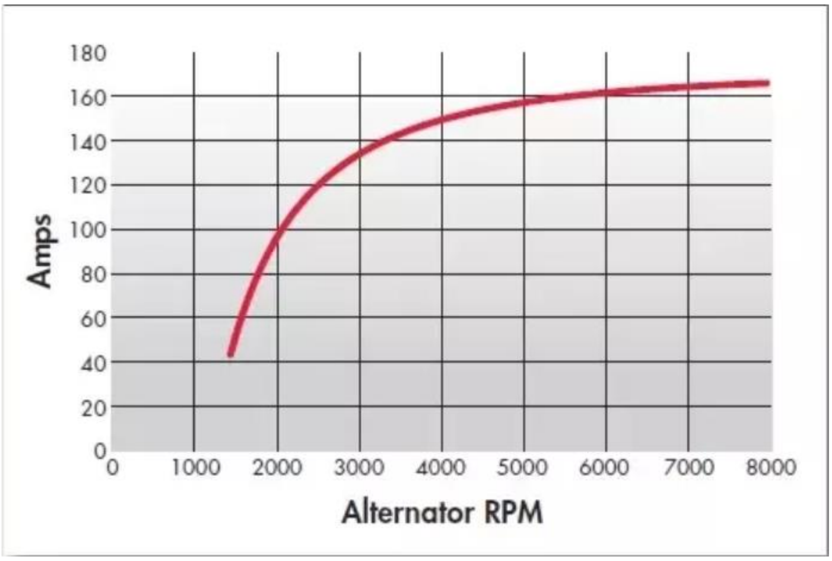


Figure 4-31 Alternator current Vs speed [19]

Figure 4-31 shows the slope of the current output of the alternator and the speed which alternator is driven. In this project the alternator rotates at 1452 RPM with approximately 50 Amp power.

H. Solar panel

Figure 4-32 shows the chosen solar panel for the project, with a 2.5 Amp and 6 Volts production power. Table 4-6 gives a detailed list of specification of this solar panel.

Figure 4-32: 6-volt 2.5-amp solar panel

Table 4-6: 6-volt 2.5-Amp solar panel specifications

Solar size	350 · 350 · 17 mm
Connecting wearing	4.3 m
Peak power pM	15 W
Maximum power voltage (VMP)	6V
Maximum power current (IMP)	2.5 A
Open circuit voltage (VOC)	6.48 V
Short circuit current (ISC)	2.8 A
Working temperature	-45 to +85 c
Tolerance Q1	$\pm$ 5%

4.2.2 Prototype calculation

The project load requires 5 volts and 3 amperes. To determine the energy consumption, we need to consider both voltage and current:

$$Energy\ per\ hour: 5\ volts\ x\ 3\ amperes\ =\ \mathbf{15\ Wh}$$

$$Energy\ for\ 2\ hours: 15\ Wh/hour\ x\ 2\ hours\ =\ \mathbf{30\ Wh}$$

Therefore, the load consumes 30 Wh over two hours, averaging a power consumption of 15 watts (W) (30 Wh / 2 hours).

The size of such batteries supplies the 30-watt load for 2 hours at maximum, therefore it'll supply the devices with the power needed.

- battery capacity 108 Wh to get the optimum design:

$$\boldsymbol{Battery\ Power\ capcaity = 108\ Wh}$$

$$\boldsymbol{Battery\ current\ per\ hour = 9\ ah}$$

In order to get a battery with a capacity of 108 Wh charged once per day, the energy supplied by PV’s must equal to 22-Watt hour minimum.

1) To calculate the power required to charge the battery system, the voltage and charge current of battery are needed for the calculations.

2) The battery average voltage from the data sheet above is approximate to 12 volts.

$$\textbf{Voltage of battery} = \mathbf{12}\ \boldsymbol{V}$$

3) The discharging current of the battery is 9 amperes maximum.
4) By multiplying the nominal voltage (V_n) by the charging current ($I_{charging}$) needed to supply the battery, the power required to charge the battery is calculated (P):

$$\begin{aligned} P &= V_n \cdot I_{charging} \\ &= 12 \cdot 4.5 \\ &= \mathbf{54}\ \boldsymbol{W} \end{aligned} \tag{4}$$

The battery requires at least 2 hours to fully charge when receiving 54 watts of power.

$$54\ watt \cdot 2\ hours = 108\ watt\ per\ day$$

Therefore, the minimum wattage to supply by the solar panels should be at least 108 watt per day. The 2 hours which is the average charging time in optimum conditions (e.g. average daily sunlight hours).

Two solar panels produce 12 volt and 5 ampere per hour. Thus, the produced power is calculated as follows:

$$\begin{aligned} P &= V_s \cdot I_s \\ &= 12 \cdot 5 \\ &= \mathbf{60}\ \boldsymbol{W} \end{aligned} \tag{4}$$

So, two solar panels fully charge a battery with a capacity of 108 Wh in two hours, in addition to producing power of up to 60 W.

4.2.3 *Prototype control*

Figure 4-33 illustrates the different networks needed (ladder diagram).

- **Network 1**

  Network one shows the normally open switch which start the machine (I0.5) and the normally open switch which stop the machine (I0.6), memory (M0.0) which gives the other networks the start operation and stop all system.

- **Network 2**

  Network two which sets the memory (M0.0) for starting and stopping the system. The grid relay closes which gives the grid power to the load with latch output (Q0.3) which keeps the operation ongoing, until stop grid (I0.1) button is pressed which means the grid power interrupts the output (Q0.3) grid and the supply.

- **Network 3**

  Network three shows the (M0.0) for starting the system. With (I0.3) switch which gives the battery state of charge, the switch output (Q0.3) grid relay which normally close that monitor battery connection. The output of the network shows the state of battery relay switch.

- **Network 4**

  Network four which states the operation of controlling the battery discharge state with normally open (I0.4) bat discharge. Also, the switch (Q0.3) controls the grid relay to disconnect it. Finally, the generator switch (Q0.0) output controls the generator relay.

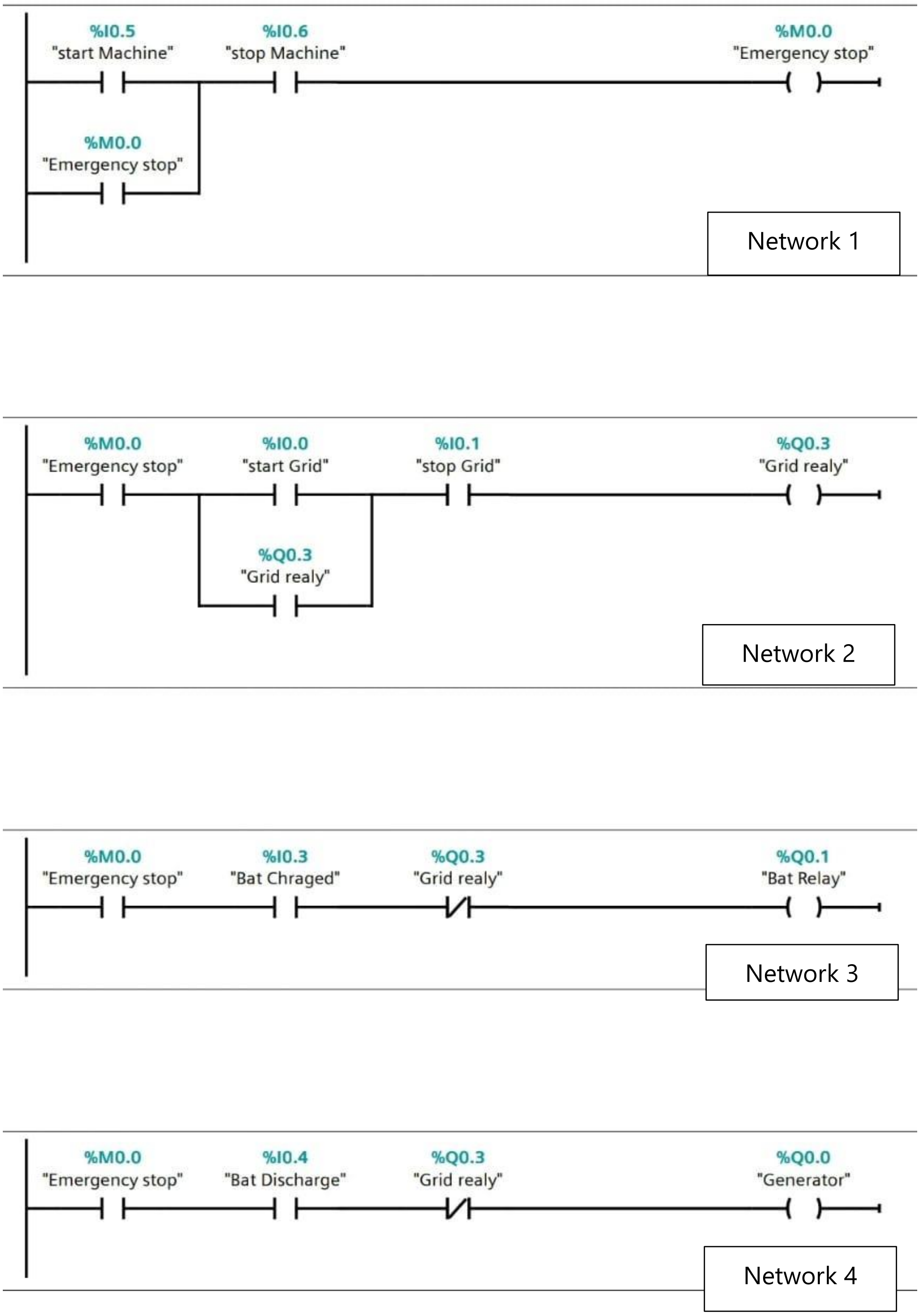


Figure 4-33 PLC ladder diagram

- *Prototype Drawing using SolidWorks CAD* (see Annex 9 for side views):

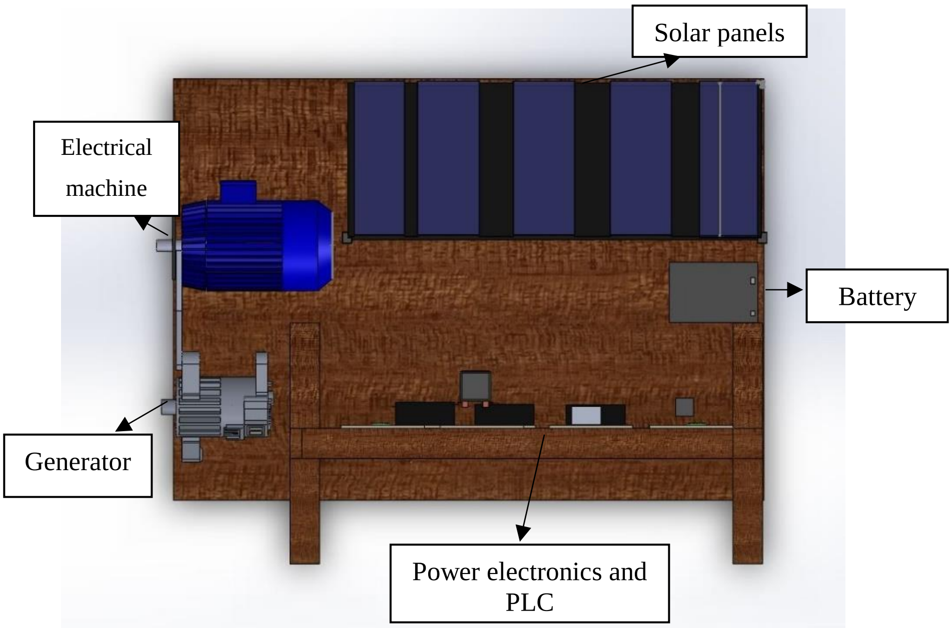


Figure 4-34 Top view of the system (*SolidWorks CAD*)

4.2.4 Prototype working principle

This project aims to obtain a continuous electric current, this project targets important devices in our daily lives. Therefore, we embodied the project in a prototype that represents the system. This process takes place through several sequential stages according to the state of the current flow in the circuit. The circuit remains the same when an electric current pass through the circuit starting from the grid electricity to the load. In the case of a power outage coming from the grid, the PLC gives a signal to grid relays to open and gives another signal to the battery relay to close the battery circuit. This process starts with the battery that is charged through the solar panel, ending with the target load. If the battery voltage is reduced because of using it for a period of time, the voltage will decrease after the PLC gives a signal to the battery relay to open and close the generator relay. This is in order to operate the circuit of the generator which starts with the generator consisting of an alternator with motor, and ends with the load.

4.2.5 *Prototype belt design*

$$LP = \mathbf{780\ mm/25.4}$$

$= 30.7\ inch$ (from table $17 - 10\ when\ lp\ = 30.4\ in\ D = 100\ = 3.94\ in$)

$$HP = \mathbf{1\ hp}$$

- V-belt type (A) from table 17-2 [20]

$$Width = \mathbf{0.56\ in}$$

$$n\ =\ \mathbf{1452\ RPM}$$

- The tow belts the same diameter.

$$V = \frac{n\ \cdot\ \pi \cdot D}{12} \tag{7}$$

$$V = \frac{3.14\ \cdot\ 3.94\ \cdot\ 1452}{12} = \mathbf{1496.96\ ft/m}$$

- When the belt Type is (A)

$$LP = L + Lc \tag{8}$$

$$LP = 31 + 1.3 = \mathbf{32.3\ in}$$

$$C = 0.25\ \cdot\ ((lp - \frac{\pi}{2}(D + d) + \left(\left(lp - \frac{\pi}{2}(D + d)^2 - 2(D - d)^2\right)^{\frac{1}{2}}\right) \tag{9}$$

$$C = 0.25\ \cdot\ ((32.3 - \frac{\pi}{2}(3.94 + 3.94) + \left(\left(32.3 - \frac{\pi}{2}(3.94 + 3.94)^2 - 2(3.94 - 3.94)^2\right)^{\frac{1}{2}}\right)$$

$$= \mathbf{9.96\ in}$$

$$Ha = K1\ \cdot K2\ \cdot\ Htab \tag{10}$$

- **K1 = 1** from table 17-13 V-belt [20]
- **K2 = 0.85** from table 17-14 A-belt [20]
- **Htab = 1.31** & **V = 1500 ft/min**, **D = 4 in** belt type A.

$$Ha = 1 * 0.85 * 1.31 = \mathbf{1.12\ hp}$$

$$nd = \frac{Ha}{Hnom \cdot Ks} \quad (11)$$

$$nd = \frac{1.12}{1} = \mathbf{1.12}$$

$$Fc = kc\left(\frac{V}{1000}\right)^2 \quad (12)$$

- From table 17-16 [20]:
  - **Kc = 0.561**
  - **Kb = 220**

$$Fc = 0.561 \cdot \left(\frac{1496.96}{1000}\right)^2 = \mathbf{1.26\ lbf}$$

- $*Hd = Ha$

$$\triangle F = \frac{63025^{\frac{Hd}{nb}}}{n\left(\frac{d}{2}\right)} \quad (13)$$

$$\triangle F = \frac{63025^{\frac{1.12}{1}}}{1452\left(\frac{3.94}{2}\right)} = \boldsymbol{24.677\ lbf}$$

$$F1 = Fc + \frac{\triangle F \cdot exp\ (f\theta)}{\exp(f\theta) - 1} \quad (14)$$

$$F1 = 1.26 + \frac{24.677\ (4.99)}{4.99-1} = \mathbf{32.1\ lbf}$$

- T1 = T2 (because the shaves diameter is same)

$$T1 = T2 = F1 + \frac{Kb}{D} \tag{15}$$

$$T1 = T2 = 32.1 + \frac{220}{3.94} = \mathbf{87.94\ \ lbf.in}$$

$$Np = \left[\left(\frac{K}{T1}\right)^{-b} + \left(\frac{K}{T2}\right)^{-b} \right]^{-1} \tag{16}$$

- From table 17-17 [20]
    - **K = 674**
    - **V = 11.089 ft/min.**

$$Np = \left[\left(\frac{674}{87.94}\right)^{-11.089} + \left(\frac{674}{87.94}\right)^{-11.089}\right]^{-1} = \mathbf{3.2\ \cdot\ 10^9}$$

$$t = \frac{Np\ \cdot\ Lp}{720\ \cdot\ V} \tag{17}$$

$$\frac{3.2\ \cdot\ 10^9\ \cdot\ 32.3}{720\ \cdot\ 1496.96} = \mathbf{95898\ hrs}$$

4.3 *COST ANALYSIS*

The main advantage of HPS system is the cost which can be affordable everywhere to implement the task of supplying the power at the cheapest price, compared to conventional power systems., because this system combines multiple types of power generation sources and is not fully dependent on one source.

4.3.1 Cost of the HPS system elements

A. Cost of panels by number

The solar panels cost depends on how many panels needed to supply the required load and to reduce Quantum power need it. The table below (Table 4-7) demonstrates the relationship between the cost to number of panels.

Table 4-7 Approximate price of good quality panels (tier 1 panels) [21]

Number of panels	Cost
4	$2,500
6	$3,000
8	$3,500
11	$4,000
14	$4,500
18	$5,000
19	$6,500
22	$7,500
27	$8,000

B. Cost of battery bank

Solar batteries usually used are of the lithium-ion type, and they cost an estimated price of 900 - 1200$ for a 10kWh, considering the price of 100$ per 1 kWh [22].

The cost of installation of batteries for solar systems depends on the manufacturer, the type of battery (chemistry), the number of batteries used for the system, the essential future upgrades, labor cost, and the regions providing government or utility incentives [23].

C. Cost of controller

In this project, a Delta programmable logic controller (PLC) with 14 inputs and 14 outputs is chosen to control the system. it was selected because it can handle the project's specific voltage and current requirements. The total cost of the PLC and the actuators for this setup is about $750.

D. Approximate price of electrical generator

Generator installations for houses usually cost from $6,000 to $11,000, with the generator costing between $3,000 and $6,000. It can reach $16,000 for big generators (30 – 48 kW). Labor costs can be between $3,000 to $5,000 for standard installations. However, complex setups with longer distances (> 20 kW systems) can significantly increase labor costs, which can be more than $12,000 [7].

Figure 4-35 shows the cost of diesel generator by the power output.

Figure 4-35 Initial cost to install generator Vs the size of power output [24]

Different fuels can be used for power generators. Each type has advantages and disadvantages: Natural gas generators (dependent on the availability of a natural gas line), Liquid propane (LP) generators (long life span, more costly), Diesel generators (higher efficiency, low maintenance, more expensive) [24].

Table 4-8 gives an estimation of prices for the three types of generators that have power capacity of 2 to 24 kW, and does not include installation.

Table 4-8 Generator Costs By Type [24]

Fuel Type	Unit price range
Natural Gas	$6,000
Liquid Propane	$6,000
Diesel	$18,000

E. Cost of transfer switch

The transfer switch is used to control the operation of the diesel generator. Table 4-9 shows the cost of its installation.

Table 4-9 Cost to install generator transfer switch by type [24]

Type	Average Total Cost
Manual	$600
Automatic	$900

F. Cost of wind turbine

Wind turbines that are used in homes and farms typically cost about 8000$ per kW. these turbines are usually under 100kW. for example, a 10kW turbine is needed to generate power for a big house, which would cost about 80 000$. Smaller turbines might seem less costly, but they're actually more expensive if we considered the energy production cost per kW [25].

According to the American Wind Energy Association (AWEA), small turbines cost about 5000$ per kW. Most houses require wind turbines with 5 - 15 kW of power capacity, which would cost approximately 25 000$ to 75 000$. Nevertheless, the estimated costs do not consider financing options and incentives. [26].

G. Cost of control circuit, wires and labor

The cost of sensors can be very different depending on the type and brand. some sensors cost 150$, while others can be quite expensive and can reach 12 000$. In addition, the project requires the use of copper wire that would cost about 1000$.

The labor cost for the installation of the system can be estimated at 15$ per hour. thus, the total cost considers the complexity of the project and the number of hours to install the whole setup.

4.3.2 *Summary cost*

Table 4-10 Summary of cost

Element	Estimated cost $
Panels (4 panels)	$2500
Battery pack	$900
Control cost	$750
Diesel generator cost	$18,000
Transfer switching automatically one	$900
Circuit of control, wires	$1150
Total estimated cost of system	**$24,400**

4.3.3 *Return investment*

A. Annual cost savings

$$Annual\ Cost\ Savings\ =\ (Grid\ Electricity\ Cost\ Savings)\ +\ (Fuel\ Cost\ Savings)$$

- Electricity Cost Savings: which represents the reduction in the annual electricity bill by using the hybrid power system.
- Fuel Cost Savings (if applicable): if a generator is conventionally used as the primary power source. It represents the annual savings on fuel used for operating the generator.

a. <u>Grid Electricity Cost Savings</u>

Assuming a 100-bed hospital consumes:

- Annual Electricity Consumption = 100,000 kWh
- Grid Electricity Rate = $0.20 /kWh
- Estimated Reduction in Grid Reliance %:
  - the Average Daily Electricity Consumption = 274 kWh (100,000kWh/365 days)

- Estimated Daily Solar Energy Production = 418.2 kWh

$$Total\ power\ output\ (W) = 440 \times 4.8W = \mathbf{2112W}$$

<u>Calculating the total power output considering efficiency:</u>

$$Total\ power\ output\ considering\ efficiency\ (W) = Total\ power\ output\ (W) \times Efficiency$$

(efficiency in Annex 2 = 19.8%)

$$Total\ power\ output\ considering\ efficiency\ (W) = 2112W \times 0.198 = \mathbf{418.176W}$$

<u>Calculating the total daily energy production:</u>

$$Total\ daily\ energy\ production\ (Wh/m^2/day) = Total\ power\ output\ considering\ efficiency\ (W/m^2) \times Power\ density\ (W/m^2)$$

$$Total\ daily\ energy\ production\ (Wh/m^2/day) = 418.176W \times 1000W/m^2 = \mathbf{418,176\ Wh/m^2/day}$$

<u>Converting from Wh to kWh:</u>

$$Total\ daily\ energy\ production\ (kWh/m2/day) = Total\ daily\ energy\ production\ (Wh/m2/day)\ /\ 1000$$

$$Total\ daily\ energy\ production\ (kWh/m2/day) = 418{,}176\ /\ 1000 = \mathbf{418.176\ kWh/m^2/day}$$

⇨ the daily production of the PV system composed of 440 monocrystalline solar cells would be approximately **418.176 kWh**.

➔ $Reduction\ in\ Grid\ Reliance = (\frac{418.2\ kWh}{274\ kWh}) \cdot 100\% = 153\%$

153% energy needs met by PV, meaning the PV system produces 100% the daily needs + 53% excess energy used in charging the battery.

⇨ The percentage of the energy covered by the PV system is more than 100%, which means that the daily production of energy by the PV system is more than the annual needs/consumption of the building. However, this percentage is only an estimation, and achieving it can be difficult in real life, considering changing weather conditions and issues that might occur to the storage capacity of the system. Therefore, the estimated percentage may in fact be less.

Annual Grid Electricity Cost Savings:

$$\boldsymbol{Total\ Annual\ Grid\ Cost\ =\ 100000\ kWh\ *\ \$0.2/kWh\ =\ \$2000}$$

$$\boldsymbol{Annual\ Savings\ =\ \$2000\ *\ 1.53\ =\ \$3060}$$

b. <u>Fuel Cost Savings</u>

Assuming a generator with an energy output of 20kW operating on full load

- Average Generator Fuel Consumption = 6 liters/hour
- Estimated Annual Reduction in Runtime = 5000 hours
- Fuel Cost = $1.2/liter

Annual Fuel Cost Savings:

$$\boldsymbol{Total\ Annual\ Fuel\ Saved\ =\ 6\ liters/hour\ *\ 5000\ hours\ =\ 30\ 000\ liters}$$

$$\boldsymbol{Annual\ Savings\ =\ 30\ 000\ liters\ *\ \$1.2/liter\ =\ \$36\ 000}$$

$$Annual\ Cost\ Savings\ =\ (Grid\ Electricity\ Cost\ Savings)\ +\ (Fuel\ Cost\ Savings)$$

$$\boldsymbol{Annual\ cost\ savings\ =\ 3060\ +\ 36\ 000\ =\ 39\ 060\$}$$

B. Calculating ROI

To calculate the return investment of this project, we need to consider the initial costs of the project and the annual savings.

The initial costs include:

- The solar panels (+ installation)
- Battery system
- Generator
- Wind turbine (if included)
- Wiring and cables
- Labor costs for installation and maintenance.

So, to estimate the return investment, the Payback Period is calculated, which is the time it takes for the project's cost savings to return the initial investment.

$$Payback\ Period\ (years)\ =\ Initial\ Investment\ /\ Annual\ Cost\ Savings$$

$$=\ \mathbf{24\,000\$\ /\ 39\,060\ =\ 0.6}\ \boldsymbol{years}\ \approx\ \mathbf{7.5}\ \boldsymbol{months}$$

Additional Considerations

- Grant Funding: Potential for grants or incentives from government programs promoting renewable energy.
- Tax Benefits: Tax credits or deductions available in some regions for installing renewable energy systems.

CONCLUSION

This project aimed at developing a hybrid power system, to be used as a potential alternative to conventional power supply systems that can be unreliable and harmful to the environment. The developed HPS can be considered in areas with potential conflicts or susceptible to natural disasters that might cause power interruptions.

the hybrid power system developed in this project converts different types of energy into electricity by replacing the conventional grid system with Photovoltaic panel system (PV), wind turbines and generators. this system can be used in critical facilities to avoid power interruptions. Such facilities can be hospitals, where the system supplies sensitive equipment with power, and where power disruption can be threatening to human safety during natural disasters, conflicts, or infrastructure damage.

the hybrid power system in this project is kept simple, and it uses clean energy sourced from the PV system and wind turbines, and stores it in battery banks to be used when needed. Despite the high initial costs, human safety is a priority and this justifies the investment, because human lives cannot be risked. although wind turbines can be expensive, they can be dispensable, and the PV system can be an affordable and sustainable alternative to it.

In the future, conventional sources of energy could be replaced by cleaner sources in all electrical appliances, taking into consideration the depletion of non-renewable energy sources that is currently happening. The hybrid power supply will be the world's future and the first step to the transformation that has already started by using clean energy for hybrid vehicles.

This study also demonstrates the practicality of this hybrid power system, especially in remote areas, which lack a grid system. In this case, the HPS can be a vital solution, helping the access to essential services such as healthcare and education. Thus, this can potentially also lead to strengthening the community and social fairness, and actually revive local economies by promoting business and connectivity.

Many studies have concluded that the use of hybrid power systems can help the environment by reducing the emission of greenhouse gases, help improve public health by having cleaner air especially in area with high air pollution, and also, it mitigates the dependence on fossil fuels due to using and prioritizing other clean energy sources. So, we conclude that this system can actually offer countless benefits.

Limitations and Future Research

While the study considered many aspects of the hybrid power system, some elements need further research

- *Battery Storage Capacity:* adequate battery storage is needed for supply in case of long continuous power interruptions. Further research can be done to enhance the battery efficiency and reduce the cost
- *Control System Complexity:* a complex control system can increase the costs of the project. More studies should consider exploring how to reduce the costs while using advanced technologies for this kind of systems.
- *Wind Turbine Integration:* the use of wind turbines in the HPS can be expensive. More strategies should be found to reduce the cost and help integrate it where it is most beneficial.
- *Large-Scale Implementation:* the use of HPS in any area should be first studied, considering the current grid system, infrastructure, policy and regulations.

SUMMARY

Hybrid Power System

Sharafeddin MALI

Mechanical Engineering MSc, full time course

Institute of Machinery and Informatics, Faculty of Mechanical Engineering

Supervisor: *Dr. Zoltán Bártfai, Associate professor, Faculty of Mechanical Engineering*

This project aims to provide a continuous power to different devices by converting different types of power as diesel mechanical generator or solar power to electrical power, which can be consumed directly or saved in battery banks to save it whenever needed. Targeting war and disaster areas also where electric power interruption occurs inutility’s power saved in batteries could be used to save lives, which ensures the sustainability of the electrical power supplied. The Project could be in different shapes and sizes depending on where it would be used. Take advantages of areas where long sunlight times the solar energy take place to supply the loads. Moreover, in the area where good active air movement the wind turbines could be used.

Diesel Generator take place also in the system when needed. It can be excluded with in necessary cases only due to its emissions (NOx, CO2) and noise pollution. The “hybrid power system supply “is controlled by a control unit and switches to the power as needed and in this project will provide a robust system switches from supply to another. This ensures a robust and reliable power supply even during unpredictable situations.

The cost estimation is covered in this project considering people’s lives are more important, providing uninterrupted power in critical situations.

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ANNEXES

Annex 1: The Vanguard lithium-ion battery

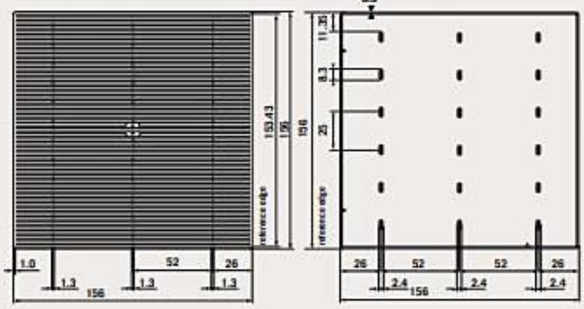
- Vanguard Battery pack data sheet:

TECHNCIAL SPECS	48v 5kWh Battery	48v 10kWh Battery
NOMINAL VOLTAGE	50.4V	50.4V
TOP VOLTAGE	57.4V	57.4V
CUTOFF VOLTAGE	37.5V	37.5V
CAPACITY AT MAX DISCHARGE (Ah/kWh)	90Ah / 4.5kWh	180Ah / 9.0kWh
NOMINAL CAPACITY (Ah/kWh)	100Ah / 5kWh	200Ah / 10kWh
COMMUNICATION PROTOCOLS	CAN J1939 (29-bit) Plus flexible secondary CAN interface	
DISCHARGE TEMPERATURE RANGE	-40 to + 60°C	-40 to + 60°C
STORAGE TEMPERATURE RANGE	-40 to + 60°C	-40 to + 60°C
CHARGING TEMPERATURE RANGE	-10 to + 50°C	-10 to + 50°C
PARALLEL CAPABLE	Yes, up to 10 batteries	Yes, up to 10 batteries
DURABILITY HOURS/CYCLES	Up to 2000	Up to 2000
DIMENSIONS	56cm x 26cm x 36cm	56cm x 47cm x 36cm
WEIGHT	45kg	90kg
IPX RATING	IP66 + Pressure Wash	IP66 + Pressure Wash
CHARGING SYSTEM		
OUTPUT POWER	1050W	1050W
INPUT POWER	120V, 60Hz / 220, 50Hz	120V, 60Hz / 220, 50Hz
REQUIRED CHARGE TIME	6 hours	12 Hours
ON-BOARD OR STAND ALONE	Either	Either
SAFETY & COMPLIANCE		
CELL SAFETY CERTIFICATION	UL 1642	
SHIPPING CERTIFICATION	UN 38.3	
PACK COMPLIANCE & PERFORMANCE	UL/IEC	
ENVIRONMENTAL COMPLIANCE	REACH and battery directive (2006/66/EC)	
EMC/EMI COMPLIANCE	Meets FCC title 47 CFR 15 Class B & CISPR 22-10	

Annex 2: Solar cell data sheet

MECHANICAL SPECIFICATIONS

Product	Monocrystalline solar cell
Format	156 mm × 156 mm ±0.5 mm Diameter: 220 ±0.5 mm
Average thickness (Si)	200 µm ±30 µm
Front surface (–)	3 x 12 soldering pads (silver), 1.3 mm ±0.2 mm wide, Alkaline textured surface, Dark blue anti-reflecting coating (Siliziumnitrid)
Back surface (+)	3 x 6 soldering pads, 2.4 mm ±0.3 mm wide (silver), aluminium backside metallisation



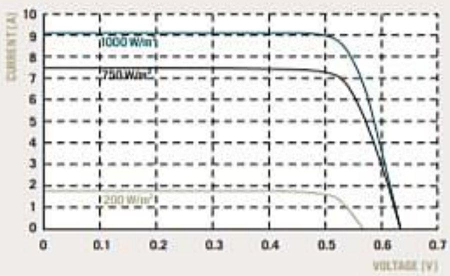
ELECTRICAL CHARACTERISTICS KENNGRÖSSEN

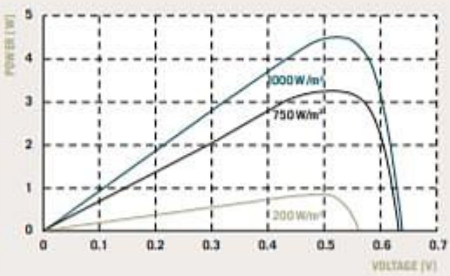
PERFORMANCE AT STANDARD TEST CONDITIONS, STC: 1000 W/m², 25 °C, AM 1.5 G (IEC 60904-3 ED.2)

POWER CLASS			4.43	4.48	4.53	4.58	4.62	4.67	4.72	4.77	4.82
Nominal power	P_{MPP}	[W]	≥4.43	≥4.48	≥4.53	≥4.58	≥4.62	≥4.67	≥4.72	≥4.77	≥4.82
Ø Short Circuit Current	I_{SC}	[A]	9.07	9.11	9.15	9.19	9.23	9.27	9.31	9.35	9.39
Ø Open Circuit Voltage	V_{OC}	[mV]	632	634	636	637	639	641	642	643	644
Efficiency*	η	[%]	≥18.2	≥18.4	≥18.6	≥18.8	≥19.0	≥19.2	≥19.4	≥19.6	≥19.8

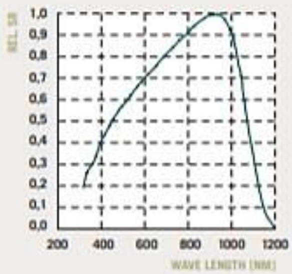
* Measurement tolerances: ±1.5% rel. (P_{MPP}); ±0.2% abs. (η); ±5% rel. (I_{SC}, V_{OC})

TYPICAL CURRENT-VOLTAGE AND POWER-VOLTAGE CURVES





SPECTRAL RESPONSE



INTENSITY DEPENDENCE

INTENSITY W/m²	V_{MPP}*	I_{MPP}*
1000	1.000	1.0
800	0.996	0.8
500	0.984	0.5
400	0.976	0.4
300	0.966	0.3
200	0.947	0.2
100	0.911	0.1

* Ratio of V_{MPP} (I_{MPP}) at reduced intensity V_{MPP} (I_{MPP}) at 1000 W/m²

TEMPERATURE COEFFICIENTS

Power	–0.42%/K
Current	+0.05%/K
Voltage	–0.33%/K

PROCESSING RECOMMENDATION

Solder joint	Copper ribbons coated with 10 – 15 µm: 62% Sn / 36% Pb / 2% Ag
Cells per bypass diode	Maximum 20 cells per bypass diode

* We recommend an electro luminescence based outgoing inspection as well as a visual inspection of the cell distances.

Annex 3: Technical data SITOP PUS 100S for different models

- Input

	6EP1332-2BA20	6EP1333-2BA20	6EP1334-2BA20	6EP1336-2BA10
Input	1-phase, AC			
Rated voltage Ue rated	120 / 230 V			
Voltage range	85-132 / 170-264 V			85-132 / 176-264 V
automatic range switchover	Yes			
Connect/shutdown threshold, typical	80 V / 61 V	77 V / 63 V	70 V / 66 V	80 V/78 V or 160 V/155 V
Power failure buffering at Ia rated, min	20 ms	20 ms	20 ms	20 ms
Power-failure buffering	at 93 / 187 V			at 120 / 230 V
Rated line frequency	50/60 Hz			
Line frequency range	47...63 Hz			
Input current / at rated value of input voltage 120 V	1.25 A	2.34 A	4.49 A	7.5 A
Input current / at rated value of input voltage 230 V	0.74 A	1.36 A	1.91 A	3.5 A
Switch-on current limitation (+25 °C), max.	33 A	40 A	60 A	11 A
I^2t, at 120 V AC, max	0.1 A^2s	0.3 A^2s	1.6 A^2s	2.5 A^2s
I^2t, at 230 V AC, max.	0.4 A^2s	1.0 A^2s	5.6 A^2s	10 A^2s
Integrated input fuse	Fuse T 3.15 A	Fuse T 3.15 A	Fuse T 6 A	Fuse T 10 A

	6EP1332-2BA20	6EP1333-2BA20	6EP1334-2BA20	6EP1336-2BA10
Protection in the line feeder cable (IEC 898)	Recommended: Circuit breaker, C characteristic, 3 A	Recommended: Circuit breaker, C characteristic, 6 A	Recommended: Circuit breaker, C characteristic, 10 A	Recommended: Circuit breaker, C characteristic, 10 A or Circuit breaker 3RV2411-1JA10 (120 V) or 3RV2411-1FA10 (230 V)
Overvoltage strength	2.3 × Ue rated, 1.3 ms			

	6EP1322-2BA00	6EP1323-2BA00
Input	1-phase, AC	
Rated voltage Ue rated	120 / 230 V	
Voltage range	85-132 / 170-264 V	
automatic range switchover	Yes	
Connect/shutdown threshold, typical	82 V / 66 V	66 V / 63 V
Power failure buffering at Ia rated, min	20 ms	20 ms
Power-failure buffering	at 93 / 187 V	
Rated line frequency	50/60 Hz	
Line frequency range	47...63 Hz	
Input current / at rated value of input voltage 120 V	1.73 A	3.24 A
Input current / at rated value of input voltage 230 V	0.99 A	1.41 A
Switch-on current limitation (+25 °C), max.	45 A	60 A
I^2t, at 120 V AC, max.	0.3 A^2s	1.6 A^2s
I^2t, at 230 V AC, max.	1.0 A^2s	5.6 A^2s
Integrated input fuse	Fuse T 3.15 A	Fuse T 6 A
Protection in the line feeder cable (IEC 898)	Recommended: Circuit breaker, C characteristic, 3 A	Recommended: Circuit breaker, C characteristic, 6 A
Overvoltage strength	2.3 × Ue rated, 1.3 ms	

➢ Output

	6EP1332-2BA20	6EP1333-2BA20	6EP1334-2BA20	6EP1336-2BA10
Output	Regulated, isolated DC voltage			
Rated voltage value Ua rated DC	24 V			
Total tolerance, static ±	3 %	3 %	3 %	3 %
Static line regulation, approx. ±	0,1 %	0,1 %	0,1 %	0,5 %
Static load regulation, approx. ±	1 %	1 %	1 %	1 %
Residual ripple Peak-peak, max.	150 mV	150 mV	150 mV	150 mV in the load range >100 mA 300 mV in the load range up to 100 mA
Spikes peak-peak, max. (bandwidth, 200 MHz)	240 mV	240 mV	240 mV	240 mV
Adjustment range	22.8...28.0 V			24...28.0 V
Product function / output voltage can be adjusted	Yes			
Output voltage setting • Remark	Using a potentiometer			Max. 480 W
Status display	LED green for 24 V O.K.			
Signaling	Relay contact (NO contact, rating 60 V DC /0.3 A) for 24 V O.K.			
Response when switching on/off	Overshoot of Ua<720 mV			No overshoot of Ua (soft start), with the exception of a capacitive load
Starting delay, max.	300 ms	300 ms	300 ms	1.5 s

	6EP1332-2BA20	6EP1333-2BA20	6EP1334-2BA20	6EP1336-2BA10
Start delay, typ.	200 ms	160 ms	150 ms	500 ms
Voltage rise 120 V / 230 V AC max.	100 ms	100 ms	100 ms	500 ms
Voltage rise 120 V / 230 V AC typ.	15 ms	15 ms	20 ms	50 ms
Rated current Ia rated	2.5 A	5 A	10 A	20 A
Current range	0...2.5 A	0...5 A	0...10 A	0...20 A
• Remark	3 A to +45° C +60 to +70 °C; derating: 3 % Ia rated/K	6 A to +45° C +60 to +70 °C; derating: 3 % Ia rated/K	12 A to +45° C +60 to +70 °C; derating: 3 % Ia rated/K	24 A to +45° C +60 to +70 °C; derating: 5 % Ia rated/K
Output active power / typical	60 W	120 W	240 W	480 W
Overload capability (Extra Power)	3.75 A for 5 s/min	7.5 A for 5 s/min	15 A for 5 s/min	30 A for 5 s/min
Short-time overload current / for a short circuit when powering up / typical	9 A	18 A	33 A	35 A
Duration of the overload capability, overcurrent / for a short circuit while powering up	800 ms	800 ms	800 ms	100 ms
• Remark	once-only	once-only	once-only	every 2.5 s
Short-time overload current / for a short circuit in operation / typical	9 A	18 A	33 A	35 A
Duration of the overload capability, overcurrent / for a short circuit in operation	800 ms	800 ms	800 ms	100 ms
• Remark	once-only	once-only	once-only	every 2.5 s
Can be connected in parallel to increase the power rating	Yes			
Number of devices that can be connected in parallel to increase the power rating, units	2			
Output characteristic	see diagram, output characteristic for 6EP1332-2BA20 (Page 44)	see diagram, output characteristic for 6EP1333-2BA20 (Page 45)	see diagram, output characteristic for 6EP1334-2BA20 (Page 45)	see diagram, output characteristic for 6EP1336-2BA20 (Page 45)
Capacitive load, max.	2 mF/A			

	6EP1322-2BA00	6EP1323-2BA00
Output	Regulated, isolated DC voltage	
Rated voltage value Ua rated DC	12 V	
Total tolerance, static ±	3 %	3 %
Static line regulation, approx. ±	0,1 %	0,1 %
Static load regulation, approx. ±	1 %	1 %
Residual ripple Peak-peak, max.	150 mV	150 mV
Spikes peak-peak, max. (bandwidth, 200 MHz)	240 mV	240 mV
Adjustment range	11.5...15.5 V	
Product function / output voltage can be adjusted	Yes	
Output voltage setting	Using a potentiometer	
Status display	LED green for 12 V O.K.	
Signaling	Relay contact (NO contact, rating 60 V DC /0.3 A) for 12 V O.K.	
Response when switching on/off	Overshoot of Ua<360 mV	
Starting delay, max.	300 ms	300 ms
Start delay, typ.	180 ms	170 ms
Voltage rise 120 V / 230 V AC max.	100 ms	100 ms
Voltage rise 120 V / 230 V AC typ.	10 ms	10 ms
Rated current Ia rated	7 A	14 A
Current range • Remark	0...7 A +55...+70 °C derating: 5 % Ia rated/K	0...14 A +55...+70 °C derating: 5 % Ia rated/K
Output active power / typical	84 W	168 W
Overload capability (Extra Power)	10.5 A for 5 s/min	21 A for 5 s/min
Short-time overload current / for a short circuit when powering up / typical	26 A	48 A
Duration of the overload capability, overcurrent / for a short circuit while powering up • Remark	800 ms once-only	800 ms once-only
Short-time overload current / for a short circuit in operation / typical	26 A	48 A

Annex 4: PLC SIMENS S7-1200 specifications

Article number	6ES7212-1AE40-0XB0 CPU 1212C ,DC/DC/DC, 8DI/6DO/2AI	6ES7212-1BE40-0XB0 CPU 1212C, AC/DC/Relay, 8DI/6DO/2AI	6ES7212-1HE40-0XB0 CPU 1212C, DC/DC/Relay, 8DI/6DO/2AI
General information			
Product type designation	CPU 1212C DC/DC/DC	CPU 1212C AC/DC/relay	CPU 1212C DC/DC/relay
Firmware version	V4.5	V4.5	V4.5
Engineering with			
• Programming package	STEP 7 V17 or higher	STEP 7 V17 or higher	STEP 7 V17 or higher
Supply voltage			
Rated value (DC)			
• 24 V DC	Yes		Yes
permissible range, lower limit (DC)	20.4 V		20.4 V
permissible range, upper limit (DC)	28.8 V		28.8 V
Rated value (AC)			
• 120 V AC		Yes	
• 230 V AC		Yes	
permissible range, lower limit (AC)		85 V	
permissible range, upper limit (AC)		264 V	
Reverse polarity protection	Yes		Yes
Line frequency			
• permissible range, lower limit		47 Hz	
• permissible range, upper limit		63 Hz	
Load voltage L+			
• Rated value (DC)	24 V		24 V
• permissible range, lower limit (DC)	20.4 V		20.4 V
• permissible range, upper limit (DC)	28.8 V		28.8 V

Input current			
Current consumption (rated value)	400 mA; CPU only	80 mA at 120 V AC; 40 mA at 240 V AC	400 mA; CPU only
Current consumption, max.	1 200 mA; CPU with all expansion modules	240 mA at 120 V AC; 120 mA at 240 V AC	1 200 mA; CPU with all expansion modules
Inrush current, max.	12 A; at 28.8 V DC	20 A; at 264 V	12 A; at 28.8 V
I^2t	0.5 $A^2 \cdot s$	0.8 $A^2 \cdot s$	0.8 $A^2 \cdot s$
Output current			
for backplane bus (5 V DC), max.	1 000 mA; Max. 5 V DC for SM and CM	1 000 mA; Max. 5 V DC for SM and CM	1 000 mA; Max. 5 V DC for SM and CM
Encoder supply			
24 V encoder supply			
• 24 V	L+ minus 4 V DC min.	20.4 to 28.8V	L+ minus 4 V DC min.
Power loss			
Power loss, typ.	9 W	11 W	9 W
Memory			
Work memory			
• integrated	75 kbyte	75 kbyte	75 kbyte
• expandable	No	No	No
Load memory			
• integrated	2 Mbyte	2 Mbyte	2 Mbyte
• Plug-in (SIMATIC Memory Card), max.	with SIMATIC memory card	with SIMATIC memory card	with SIMATIC memory card
Backup			
• present	Yes	Yes	Yes
• maintenance-free	Yes	Yes	Yes
• without battery	Yes	Yes	Yes
CPU processing times			
for bit operations, typ.	0.08 µs; / instruction	0.08 µs; / instruction	0.08 µs; / instruction
for word operations, typ.	1.7 µs; / instruction	1.7 µs; / instruction	1.7 µs; / instruction
for floating point arithmetic, typ.	2.3 µs; / instruction	2.3 µs; / instruction	2.3 µs; / instruction

CPU processing times			
for bit operations, typ.	0.08 µs; / instruction	0.08 µs; / instruction	0.08 µs; / instruction
for word operations, typ.	1.7 µs; / instruction	1.7 µs; / instruction	1.7 µs; / instruction
for floating point arithmetic, typ.	2.3 µs; / instruction	2.3 µs; / instruction	2.3 µs; / instruction
CPU-blocks			
Number of blocks (total)	DBs, FCs, FBs, counters and timers. The maximum number of addressable blocks ranges from 1 to 65535. There is no restriction, the entire working memory can be used	DBs, FCs, FBs, counters and timers. The maximum number of addressable blocks ranges from 1 to 65535. There is no restriction, the entire working memory can be used	DBs, FCs, FBs, counters and timers. The maximum number of addressable blocks ranges from 1 to 65535. There is no restriction, the entire working memory can be used
OB			
• Number, max.	Limited only by RAM for code	Limited only by RAM for code	Limited only by RAM for code
Data areas and their retentivity			
Retentive data area (incl. timers, counters, flags), max.	14 kbyte	14 kbyte	14 kbyte
Flag			
• Size, max.	4 kbyte; Size of bit memory address area	4 kbyte; Size of bit memory address area	4 kbyte; Size of bit memory address area
Local data			
• per priority class, max.	16 kbyte; Priority class 1 (program cycle): 16 KB, priority class 2 to 26: 6 KB	16 kbyte; Priority class 1 (program cycle): 16 KB, priority class 2 to 26: 6 KB	16 kbyte; Priority class 1 (program cycle): 16 KB, priority class 2 to 26: 6 KB
Address area			
Process image			
• Inputs, adjustable	1 kbyte	1 kbyte	1 kbyte
• Outputs, adjustable	1 kbyte	1 kbyte	1 kbyte
Hardware configuration			
Number of modules per system, max.	3 comm. modules, 1 signal board, 2 signal modules	3 comm. modules, 1 signal board, 2 signal modules	3 comm. modules, 1 signal board, 2 signal modules
Time of day			
Clock			
• Hardware clock (real-time)	Yes	Yes	Yes
• Backup time	480 h; Typical	480 h; Typical	480 h; Typical
• Deviation per day, max.	+60 s/month at 25 °C	+60 s/month at 25 °C	+60 s/month at 25 °C

Specifications

Digital modules (output/input/mix): 8 ,16 , 32, 64 I/O

Analog modules (output/input/mix): 2 channel, 4 channel, 6 channel inputs (14-bit) / output (12-bit)

Load cell modules: independent dual-channel high speed high accuracy load cell module with 24 bits resolution with 2.5ms response rate

Temperature measurement modules: conversion time 200ms/channel, overall accuracy+/-0.6%, resolution 16bits, RTD inputs: Pt100 / Pt1000 3850 PPM/°C (DIN 43760 JIS C1604-1989) / Ni100 / Ni1000 / LG-Ni1000 / Cu100 / Cu50, thermocouple inputs: J, K, R, S, T type

Network modules: Ethernet, DeviceNet, PROFIBUS-DP,CANopen,RS-485,RS-422,BACnet MS/TP

Remote I/O communication modules: DeviceNet, PROFIBUS, Ethernet (MODBUS TCP), RS-485 (MODBUS ASCII/RTU)

Annex 5: Arduino Uno data sheet

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5V
Recommended Input Voltage	7-12V
Input Voltage Limits	6-20V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 KB (0.5 KB is used for Bootloader)
SRAM	2 KB
EEPROM	1 KB
Frequency (Clock Speed)	16 MHz

Annex 6: Arduino IDE code for voltage sensors and relay opening

```
//screen define
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

// Define analog input
#define SIGNAL_PIN A0

// Floats for ADC voltage & Input voltage
float adc_voltage = 0.0;
float in_voltage = 0.0;

 //sensor code detecat voltage
// Floats for resistor values in divider (in ohms)
float R1 = 30000.0;
float R2 = 7500.0;

// Float for Reference Voltage
float ref_voltage = 5.0;

// Integer for ADC value
int adc_value = 0;
const int relayPin = 4;

// Initialize the LCD library with I2C address and LCD size
LiquidCrystal_I2C lcd (0x27, 16,2);

void setup()
{
  // Setup Serial Monitor
  Serial.begin(9600);
  pinMode(relayPin, OUTPUT);
  int adc_value = analogRead(A0);
  Serial.println ("Voltage sensor Test");
  // Initialize the LCD connected
  lcd. init ();
// Turn on the backlight on LCD.
  lcd. backlight ();
  lcd.print ("HPS ARDUINO");
  lcd. setCursor (0, 1);
  lcd.print ("VOLTAGE SENSOR..");
delay(3000);
lcd.clear();
}

void loop() {

  adc_value = analogRead(SIGNAL_PIN);

  // Determine voltage at ADC input
  adc_voltage  = (adc_value * ref_voltage) / 1024.0;

  // Calculate voltage at divider input the (0.07) it error between actual read and calcualted one
  in_voltage = (adc_voltage / (R2 / (R1 + R2)))+0.07 ;

  // Print results to Serial Monitor to 2 decimal places
  Serial.print("Input Voltage = ");
  Serial.println(in_voltage, 2);

  lcd. setCursor (0, 0);
  lcd.print ("VOLTAGE MEASURED");
//Here cursor is placed on second line
  lcd. setCursor (0, 1);
  lcd.print (in_voltage, 2);
  lcd.print (" volts");
```

```
  Serial.println(" ");

// the loop which gives the realy the state of charge of the battery

if ( in_voltage < 11){


   digitalWrite(relayPin, LOW);

  } else {
    digitalWrite(relayPin, HIGH);
  }{
  }
 delay(500);
 }
```

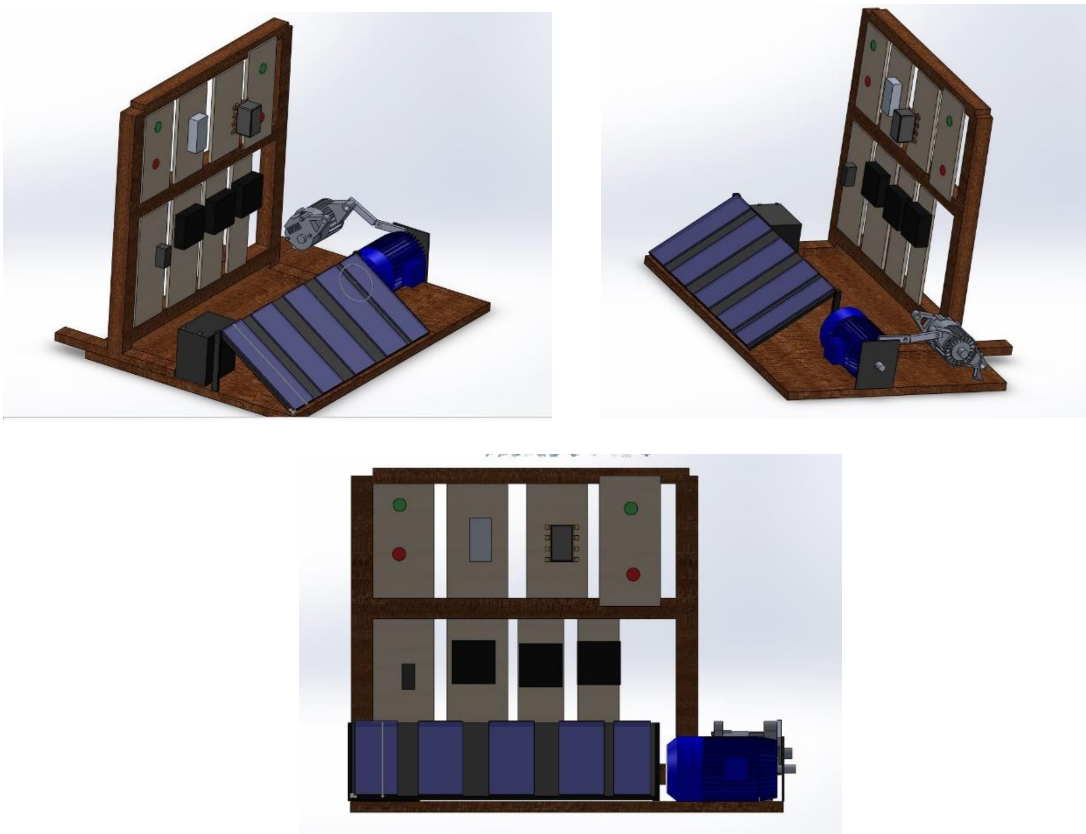
Annex 7: Motor data sheet

Product group	Squirrel-cage rotor, IEC/DIN
Rated output	0.06 kW to 500 kW (IE1-, IE2-, IE3-versions with 2, 4, 6 and 8 poles)
Sizes	56 to 355
Efficiency classification/ efficiency determination	IEC/EN 60034-30-1 / IEC/EN 60034-2-1, ≤ 1 kW direct measurement, > 1 kW residual loss method
Housing material	Grey cast iron
Rated torque	0.4 Nm to 3600 Nm
Method of connection	Single-speed motors are designed in star-delta configuration as standard.
Stator winding insulation	Thermal class 155, optional 155 [F(B)], 180 to IEC/EN 60034-1
Degree of protection	IP 55 to IEC/EN 60034-5, optionally IP 56 or higher
Type of cooling	IC 411, IC 416, IC 71W (IC 31W) to IEC/EN 60034-6
Coolant temperature/ installation altitude	Standard -20 °C to +40 °C, Altitude 1000 m above sea level
Rated voltage	Standard voltages to EN 60038 50 Hz: 230 V, 400 V, 500 V, 690 V, 60 Hz: 275 V, 460 V, 480 V, 600 V Voltage ranges A and B to IEC/EN 60034-1 (230 V, 50 Hz and 275 V, 60 Hz from size 315 prior consultation necessary)
Duty types	S1, continuous duty, Short-time duty S2, 10/30/60 min Duty type S3/S6, 25/40/60 %c.d.f.
Types of construction	IM B3, IM B35, IM B5 and derived types to IEC/EN 60034-7
Paint finish	Normal finish “Moderate”, colour RAL 7031, blue-grey Special finish “Worldwide”, colour RAL 7031, blue-grey
Vibration severity grade	Grade “A” as standard for machines with no special vibration requirements
Shaft ends	to DIN 748 (IEC 60072), balanced with half-key
Limit speeds	Please refer to the section of “Limit speeds“ in catalogue section “Motors for converter-fed operation”, Chapter 4.
Bearing design	Please refer to the tables of bearing design data.
Motor mass	Please refer to the technical selection lists.
Terminal boxes	Please refer to the section “Terminal boxes”.
Documentation	An operating and maintenance manual, a terminal plan and a safety data sheet are supplied with each motor.
Tolerances	Please refer to the section “Tolerances” in catalogue section “Introduction“, Chapter 1.

Annex 8: Alternator data sheet

Voltage: 12 VDC
Fan Type: External
Rotation Direction: Clockwise
External Fan Included: Yes
One Wire Capable: No
External Regulator Included: Yes
Case Material: Aluminum
Case Color: Aluminum
Regulator Type: Internal
New Or Remanufactured: Remanufactured

Annex 9: Prototype Drawing using SolidWorks CAD



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