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DESIGN OF A SOLAR-BASED PORTABLE POWER SUPPLY WITH MODULAR BATTERY SYSTEM FOR THE DUMAGAT TRIBE IN NORZAGARAY, BULACAN

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Abstract: **This paper aims to develop a portable power supply with a modular battery pack that is charged through a solar panel and controller that can provide the Dumagat Tribe in Norzagaray, Bulacan access to basic electric needs. Their needs were calculated using schedule of loads and the system was designed in accordance to PEC Article 6.09 (Solar PV Systems). Data was assessed by monitoring voltage levels using Arduino and statistical treatment was used to determine any significant differences in charging and discharging rates. The system is equipped with the following major components: inverter, a 12V battery pack with battery management system (BMS), a rectifier circuit, portable solar panel, solar charger controller, and a 3D-printed enclosure. Interpretation of the data shows that the charging and discharging rates of the battery during the 3-day duration of testing is fairly consistent. Hence, the following objectives were achieved: determine the energy requirements of the main outpost area of the Dumagat tribe located in Norzagaray, Bulacan, to develop a portable power supply system that will satisfy the aforementioned demands, to measure the effectiveness of the system in delivering energy to the tribe through quantitative means and provide renewable energy for lighting and basic electric purposes. The following recommendations are suggested: 1) To further improve the battery pack by using higher quality (higher capacity) 18650 battery cells to prolong usage duration, 2) To utilize a much more powerful solar panel that is preferably much more compact than the one used in this study, and 3) To try different types of batteries, such as Li-Po.**

Keywords: **Portable Power Supply, Modular Battery Pack, Solar Charger Controller, Solar Panel, Inverter, Battery Management System.**

I. INTRODUCTION

In modern times, it is undeniable that electricity is considered more of a necessity rather than a luxury. However, not all of us are fortunate enough to have access to grid-based energy sources such as MERALCO. Those who live in the most remote of areas in our country still suffer from lack of electricity; according to the World Bank in 2020, 96.84% of Filipinos had access to electricity. This leaves 3.16% of the Filipinos with no electricity (IEA, IRENA, UNSD, World Bank, & WHO, 2019). Sadly, most of the affected people are those of indigenous origins. The indigenous people of the Philippines comprise around 10 to 20% of our total population. One of those indigenous groups are the Dumagats, indigenous people who live in certain parts of Luzon (Eduardo & Gabriel, 2021). There are several studies and projects made in order to provide assistance to different branches of the Dumagat tribe scattered across Luzon. Despite living in remote areas, some Dumagat tribe communities have access to electronics and appliances such as phones, video players, and even televisions (Mabuan, 2021). This proves that even indigenous people such as the Dumagat tribe require access to electricity; which becomes a challenge when said remote areas have no access to the mainstream grid system of the country. One effective means of providing the indigenous people in remote areas with electricity is through the utilization of off-grid renewable energy. Perhaps one of the most taken for granted forms of renewable energy in the Philippines is solar energy, which only attributed to 0.02% of energy contribution together with wind energy back in 2012 (Macabebe et al., 2016). According to Macabebe et al., solar home systems are factually easier to establish in remote communities where grid connection is either too expensive or impossible. An example of a successful attempt in providing the Dumagat people energy is done by Marvin Mayo. He established an off-grid system that highly observed the economic and environmental factors that were involved in the process, including carbon dioxide payback (Mayo, 2018). Hence, the researchers aim to conduct the study with the following purposes in mind; (1) to determine the energy requirements of the Dumagat tribe located in Norzagaray, Bulacan; (2) to develop a portable power supply system that will satisfy the aforementioned demands; (3) measure the effectiveness of the system in delivering energy to the tribe through quantitative means: and (4) to safely provide energy for lighting and basic electric purposes. The study is all about the Design of a Solar-Based Portable Power Supply with Modular Battery System for the Dumagat Tribe in Norzagaray, Bulacan. The study is conducted with an aim to create a portable power supply with the innovation of a having a modular battery system. Specifically, this study aims to; (1) Determine the energy requirements of the main outpost area of the Dumagat tribe located in Norzagaray, Bulacan; (2) Develop a portable power supply system that will satisfy the aforementioned demands; (3) Measure the effectiveness of the system in delivering energy to the tribe through quantitative means; (4) Provide renewable energy for lighting and basic electric purposes.

II. METHODOLOGY

2.1 Research Design

The research design used is the quantitative research design. Quantitative research allows the researchers to gather data of numerical/measureable nature and be able to formulate answers and conclusions based on mentioned data. Quantitative research allows for a much more scientific approach in the field of engineering.

Research Locale

The research locale will be the local community of the Dumagat tribe located near the Angat Dam at Norzagaray, Bulacan. It is approximately an hour away from the nearest urban settlement and requires a transport that can traverse through tight curves and slopes surrounded by forestry and foliage. The actual settlement is just a part of a much larger community that is composed of scattered houses located around the dam reservoir; some settlements require the usage of a boat to be reached. The community of interest is the main outpost of the Dumagat tribe located around one of the reservoir of the Angat dam. Said outpost area consists of few huts made from bamboo and fibre-based bindings. It can be estimated that around 30 to 50 people are residing in the main outpost area.

Satellite view of the vicinity of the Dumagat tribe's community in Norzagaray, Bulacan

Figure 2.0 Site Location

Source: maps.google.com

2.2 Project Construction Procedure

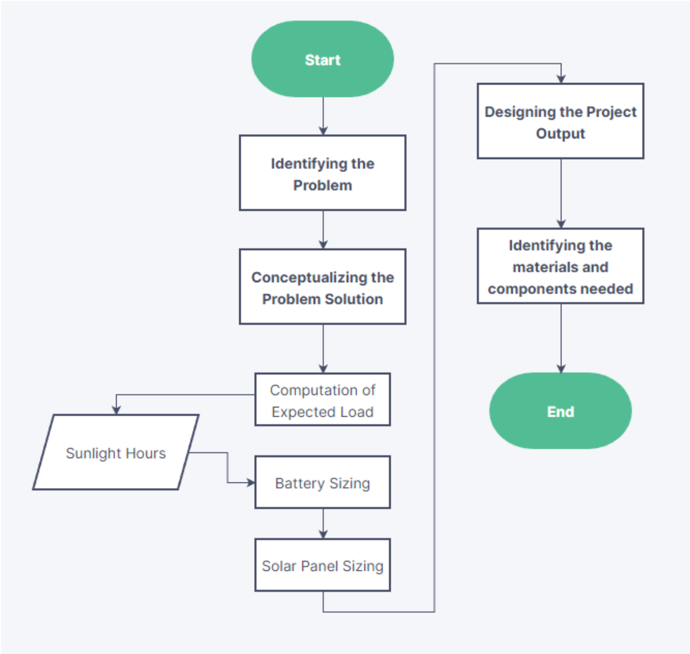

Figure 3.0 Project Construction Procedure

Identifying the Problem

To identify the problem that must be solved, the proponents of the research went to survey the actual location concerned. In this case, the problem is the Dumagat tribe's lack of access to electricity and public utilities, despite the confirmed usage of electronic devices such as phones.

Conceptualizing the Problem Solution

The proponents of the research will provide the recipients with a portable power supply powered by solar energy. In order to deliver maximum efficiency, the proponents will provide a modular battery pack system portable power supply to the recipients of the research output. By having a modular battery system, the main housing of the power supply system can remain indoors while the solar charging portion of the system is the only to be exposed to outdoor elements.

Load Analysis

Table 3.1 Schedule of Loads

LOAD	QTY.	POWER	TOTAL POWER	HRS. USED	DAILY CONSUMPTION
LED LIGHTING	1	5W	5W	12 HRS	60WH
MOBILE PHONE CHARGER	1	5W	5W	12 HRS	60WH
AUXILIARY LOAD	1	5W	5W	8 HRS	40WH
TOTAL	-	-	-	-	160WH

The schedule of load includes three main loads, namely LED lighting, mobile phone charging, and a 5W auxiliary load, as required by the stated objectives. Each load are multiplier to hours of operations and their products are summed up to get the total watt-hour daily consumption.

Panel Sizing

Calculations are done in accordance to PEC (Philippine Electrical Code 2017) Article 6.90 – Solar PhotoVoltaic (PV) Systems.

PV POWER= (Total Daily Consumption)/(Sun Peak Hours) x 1.3 (Losses)

PV POWER= 160WH/4.5 x 1.3 (Losses)

PV POWER= 46.22 Watts

No.of PV Panels=(PV Power)/(Rating of PV)= (46.22 Watts)/(180 Watts (Polycrystalline))

No.of PV Panels=0.2567≈1 pc

Use: 1 pc – 180W Polycrystalline Solar Panel

Inverter Sizing

NO MOTOR LOADS (SURGE)

Use: 1-Modified Sine Wave 12V 4000W (Surge) with 300W Continuous Power

Solar Charge Controller Sizing

$$Icc = \frac{Total\ PV\ Power}{System\ Voltage} = \frac{180W}{12V}$$

$$Icc = 15A$$

Use: 1 pc – YJSS20 12/24V Auto Adapt 20A

Battery Sizing

In order to calculate the battery capacity required, the daily consumption (in watt-hour) must be divided by the system voltage (for this study, 12V).

$$Battery\ Capacity = \frac{Total\ Daily\ Consumption}{System\ Voltage} = \frac{160W}{12.6V}$$

$$Battery\ Capacity = 12.6984\text{Ah}$$

$$Battery\ Connection\ (Parallel) = \frac{Battery\ Capacity}{Rating\ of\ Battery} = \frac{12.6984Ah}{1700mAh} = 7.46\ \approx 7$$

$$Battery\ Connection\ (Series) = \frac{System\ Voltage}{Rating\ of\ Battery} = \frac{12V}{3.7V} = 3.24\ \approx 3$$

The battery that the researchers have decided to use are 18650 3.7V 1700mAh lithium-ion batteries. In order to create a 12V system, 3 18650 batteries must be connected in series and seven parallel columns to meet the ampere-hour requirement (12Ah).

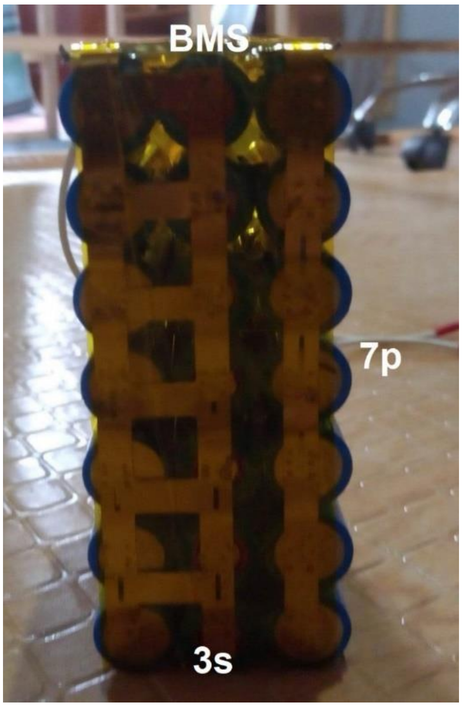

Figure 2.1 18650 Battery Configuration

Design of Alternative AC to DC Power Source

For versatility, the proponents of the study have decided to integrate an AC to DC full bridge rectifier circuit as an alternate source of charging and energy for the battery and inverter, respectively. The DC output of the rectifier is then transmitted to a DC-to-DC buck converter that ensures that the output voltage is around 13V to promote battery charging (in accordance to the BMS datasheet). The positive/negative outputs are connected in parallel with the battery pack's positive and negative terminals

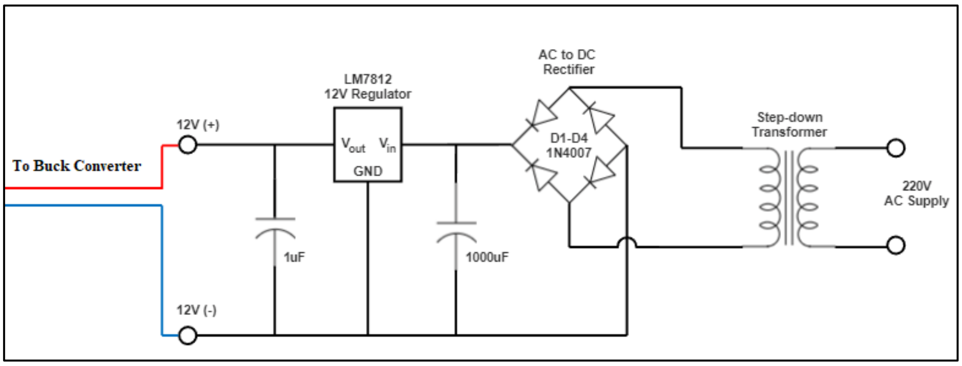

Figure 2.2 AC to DC Bridge Rectifier (Regulated) with Buck Converter

Portability of the System

According to the British Standard BS7671, a mobile/portable equipment can be defined as "an electrical equipment which is moved while in operation or which can easily be moved from one place to another while connected to the supply." On the other hand, IEC 60950-1 (International Electrotechnical Commission) defines transportable (a term preferred over "portable") as "any movable equipment that is intended to be routinely carried by a user", such as laptops. In this study, the proposed portable power supply is light and small enough to be carried around, which includes both the main unit and the solar charging module

Schematic Diagram

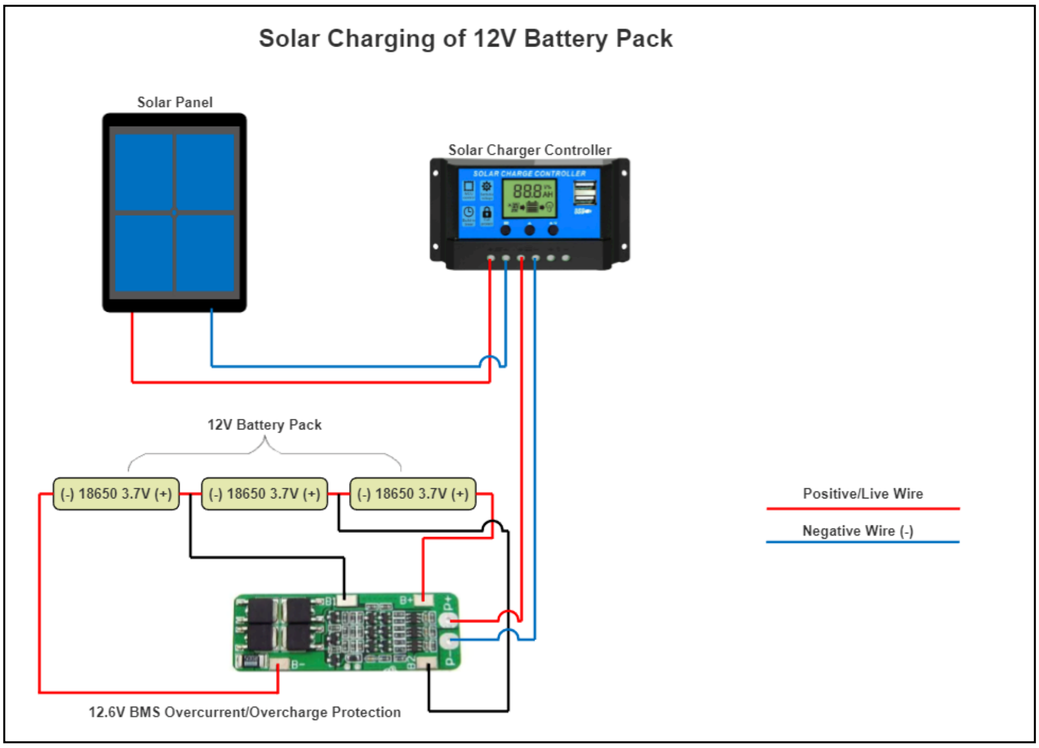

Figure 2.3 A Schematic Diagram of Solar Charging

The solar panel is connected to the solar charger controller through DC barrel plug. The battery pack is also attached to the controller through DC barrel plug, which lessens the attachment time; the original method of attaching the battery and the solar panel to the controller involves screwing the positive and negative wires manually in place.

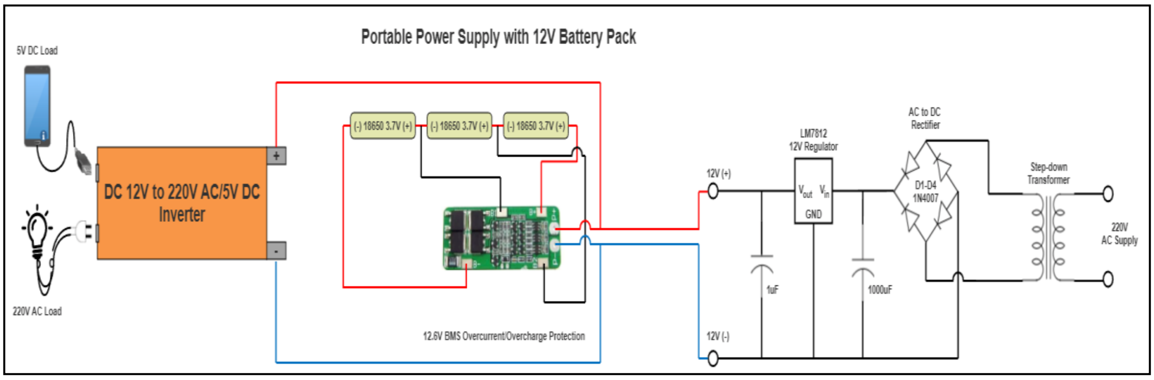

Figure 2.4 Schematic Diagram of the Power Supply

The battery pack is connected in parallel with the inverter's positive and negative terminal, and with the positive and negative output of the AC to DC rectifier. In the final output, a buck converter was put into place in between the AC to DC rectifier and the battery pack (to regulate the DC output voltage of the rectifier).

The bridge rectifier is powered by a 220V AC input, which is then stepped-down by a transformer down to 12V AC. This 12V AC is then converted into 12V DC by the full bridge rectifier and is smoothened by capacitors.

The inverter receives the 12V voltage of the battery pack's BMS. This allows the inverter to output 220V AC delivered through an AC port and 5V DC delivered through USB ports.

III. RESULT AND DISCUSSIONS

In order to achieve the main objective of this research, which is to create a portable power supply for the Dumagat Tribe in Norzagaray, Bulacan, an in-depth study and analysis was done in Chapter 3. The prototype was designed to support the following intended loads: phone charging, lighting and small auxiliary load such as Bluetooth and USB devices. The electrical design was checked and validated by Engr. Ian Ruy V. Padaoang, PEE.

3D CAD Design in Fusion360

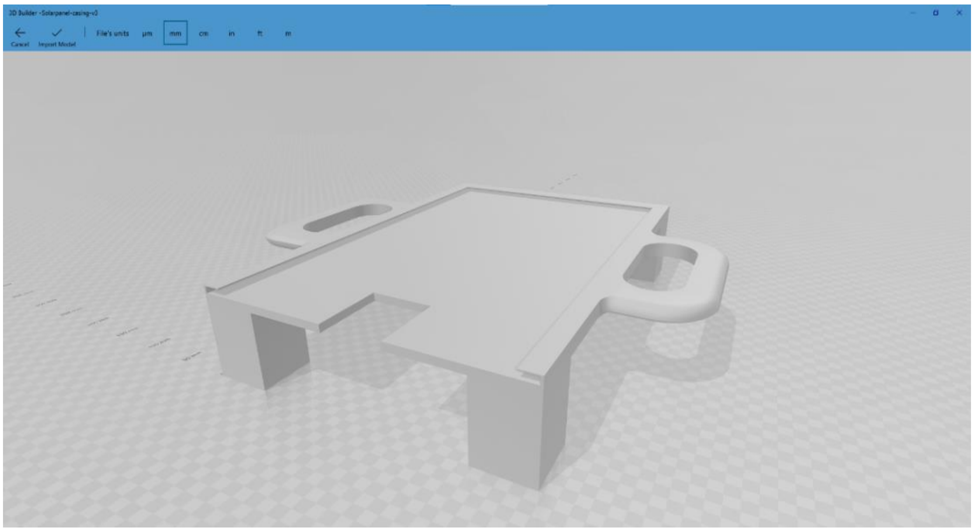

Figure 3.0A Solar Panel/Charge Controller Casing

The solar panel and charger controller holder/casing was designed in such a way that its durability will be maximized. Instead of utilizing thin legs and foldable legs, thick legs were chosen to avoid breakage due to mechanical failure. Handles were also provided for extra portability. These decisions were necessary due to the fact that the solar panel and controller will be exposed to the external environment more frequently.

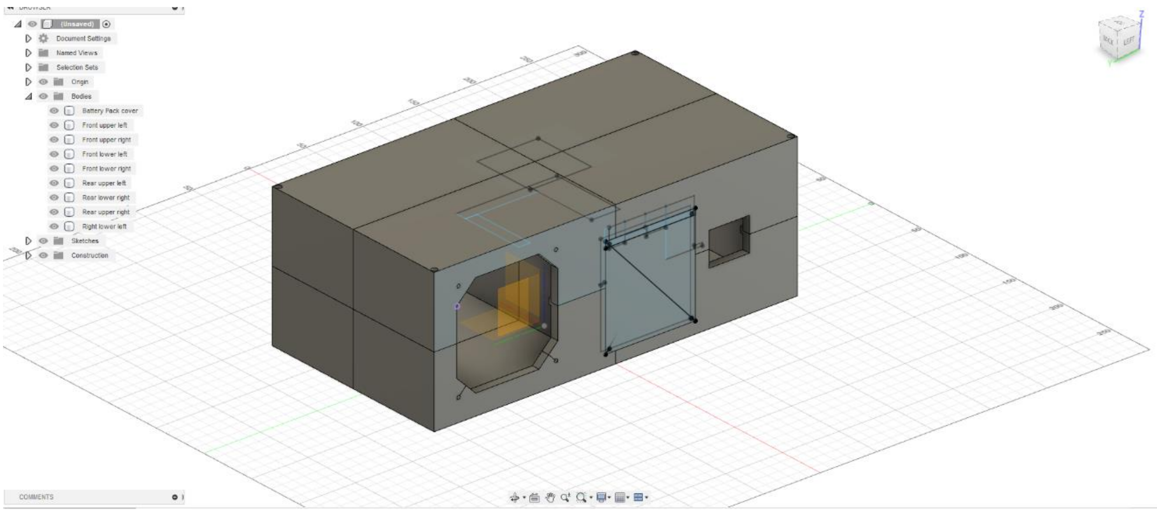

Figure 3.0B Main Housing

The main housing of the portable power supply was designed in such a way that its major components were separated into segments; reason being is that very few 3D printing services offer one-time printing of large 3D designs. The segments were assembled with epoxy, which also provides extra durability for the 3D printed materials.

Data Gathering

Data gathering was done at Sampaloc 3, Dasmariñas, Cavite instead, due to financial considerations and time restraints. The research proponents tested the battery pack and the solar charging modules for 3 days.

Parameters

Solar Charge Controller

Table 3.1 Solar Charger Controller Parameters

Parameters	Value
Float Voltage	14.4V
Discharge Reconnect	12.6V
Discharge Stop	10.7V
Type of Battery	b01 (Sealed)

Solar Charging

Table 3.2A Summary of Data Gathering for Solar Charging

DATE	WEATHER	STARTING VOLTAGE	PEAK VOLTAGE
May 22, 2023	CLOUDY/RAINY	11.78V	12.50V
May 23, 2023	CLOUDY	11.67V	12.53V
May 24, 2023	CLOUDY/SUNNY	11.56V	12.58V

First day of data gathering was done on May 22, 2023. From 9:00AM to 4:00PM, solar charging was done. However, testing was frequently interrupted by heavy rain. It was cloudy all throughout the day. The battery at the end of the day was able to reach a maximum voltage level of 12.5V

Second day of data gathering was done on May 23, 2023. The weather was mostly cloudy and rain has again disrupted the solar charging data gathering for some time. Testing was done from 12:00PM to 5:45PM. The battery pack managed to reach a peak voltage of 12.53V during this day of testing.

Second day of data gathering was done on May 23, 2023. The weather was mostly cloudy and rain has again disrupted the solar charging data gathering for some time. Testing was done from 12:00PM to 5:45PM. The battery pack managed to reach a peak voltage of 12.53V during this day of testing.

Discharging

Table 3.2B Summary of Data Gathering for Solar Charging

DATE	STARTING VOLTAGE	LOWEST VOLTAGE DROP
May 22, 2023	12.50V	11.63V
May 23, 2023	12.53V	11.56V
May 24, 2023	12.58V	11.60V

The following loads were used to discharge the battery pack through a DC to AC inverter: a 5W light bulb connected to the AC outlet, a 5W phone charger connected to USB slot 1 and a 7W ring light connected to USB slot 2. First day testing was done from 7:00PM to 1:00AM, where the battery dropped from 12.50V to 11.63V after testing

Second day testing was done from 8:30PM to 1:00AM, where the battery dropped from 12.53V down to 11.56V after testing period

Third day of testing was done from 7:00PM to 12:00AM, where the battery dropped from 12.58V down to 11.60V after testing period

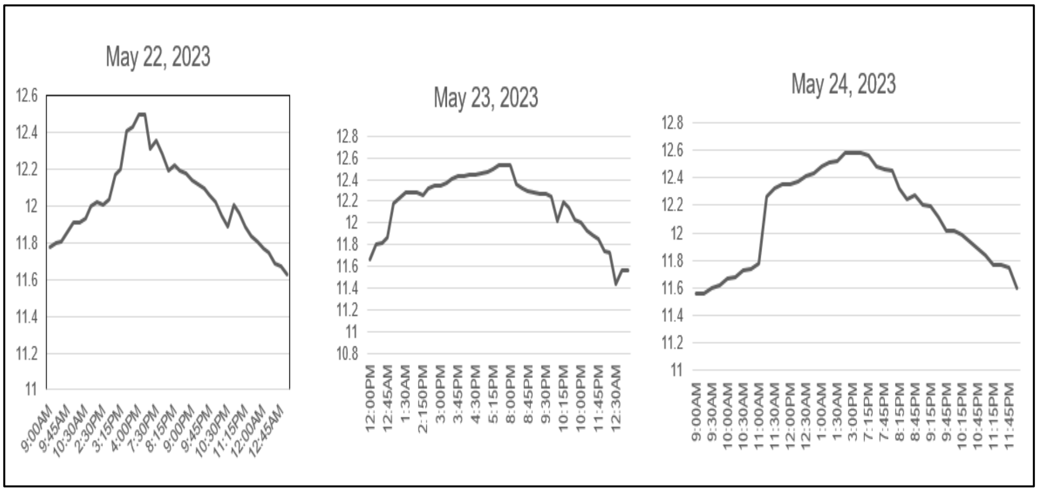

Figure 3.3 Line Graph Representations of Data Gathering

Due to cloudy and rainy conditions, it can be observed in the graphs that the charging time took a significant amount of time to fully charge, except during the 3rd where there was a spike in charging due to sunny conditions

Statistical Treatment of Data

In order to interpret the effectiveness of the system, the gathered data must undergo statistical treatment. The statistical treatment was done by Mr. Aldren B. Narzoles

Descriptive Output on the Effectiveness of the Designed Solar-Based Portable Power Supply with Modular Battery System in Terms of Charging and Discharging

Table 3.3.1 Descriptive Output on the Effectiveness of the System

Charging and Discharging	Day	N of Readings	Mean Voltage	Std. Deviation	F-value	p-value	Remarks
Charging	1	16	12.0487	0.23111	3.265*	0.055	NS
	2	24	12.2783	0.24558			
	3	21	12.1000	0.40127			
Discharging	1	25	12.0212	0.23195	0.784*	0.461	NS
	2	21	12.0314	0.30015			
	3	21	12.1157	0.29192			

*Note: ** - The test statistic (F – test) is significant at 0.05 level. * - The test statistic (F – test) is not significant at 0.05 level. For remarks, NS indicates No Significant Difference and WS indicates With Significant Difference.*

Multiple Comparisons on the Days of Charging for the Effectiveness of the Designed Solar-Based Portable Power Supply with Modular Battery System

Table 3.3.2 Comparisons on the Days of Charging

(I) Day	(J) Day	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-0.22958*	0.09856	0.060	-0.4666	0.0075
	3	-0.05125*	0.10134	0.869	-0.2950	0.1925
2	1	0.22958*	0.09856	0.060	-0.0075	0.4666
	3	0.17833*	0.09125	0.133	-0.0411	0.3978
3	1	0.05125*	0.10134	0.869	-0.1925	0.2950
	2	-0.17833*	0.09125	0.133	-0.3978	0.0411

*Note: ** - The mean difference is significant at 0.05. * - The mean difference is not significant at 0.05.*

IV. CONCLUSION

The proponents of the research entitled "Design of a Solar-Based Portable Power Supply with Modular Battery System for the Dumagat Tribe in Norzagaray, Bulacan" concludes that the portable power supply was shown capable of supplying low-energy load, such as charging mobile phones, mobile lighting and small auxiliary load such as the small AM/FM radio. There were also shortcomings such as the short lifespan of AC power whenever the battery pack reaches a certain voltage drop.

The proponents of the research therefore was able to achieve the following objectives: 1) Determine the energy requirements of the main outpost area of the Dumagat tribe located in Norzagaray, Bulacan by calculating the schedule of loads (see Table 3.1), 2) Develop a portable power supply system that will satisfy the aforementioned demands, which was done through the proper calculation of battery sizing, panel sizing, MPPT sizing, inverter sizing, and the design of the enclosure of the system, 3) Measure the effectiveness of the system in delivering energy to the tribe through quantitative means, which was done through the utilization of an Arduino-based data logger, and 4) Provide renewable energy for lighting and basic electric purposes, done through the charging and discharging testing.

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