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# SOLUPS: A Hybrid Solar Powered UPS Using Prismatic Lithium-Iron Phosphate Battery Pack

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***Abstract –*** *This study aimed to design and develop a solar-powered uninterruptible power supply (UPS) called SOLUPS, that can serve as a renewable backup power source. The study addresses related questions on the design of the SOLUPS such as the charging time, run-time, impact of other variables, and economic factors. Descriptive and developmental research methods were employed with the researchers' knowledge of electrical engineering to conceptualize the design of the SOLUPS. This study designed and developed a solar-powered uninterruptible power supply (UPS) called SOLUPS, a backup power source. Results revealed a significant effect of the load wattage on the run-time, with the 200W load wattage providing longer run-time as compared to the 350W load wattage. The load type also influences the run-time, with DC loads having a slight advantage over the AC type of load. The study concludes that the SOLUPS' design effectively addressed the research objectives and provided reliable backup power through solar energy. The charging time, run-time, and economic factors of the SOLUPS demonstrate its potential as a practical solution for power interruptions and the utilization of renewable energy. The SOLUPS is made of a 1280Wh Lithium-Iron Phosphate (LiFe PO4) battery pack with a 100Ah battery management system and a 5A capacitive active balancer. A low-voltage disconnect module is also added to protect the battery pack from draining. SOLUPS can deliver up to 800W of AC power with a pure sine wave.*

***Keywords –*** *SOLUPS, Uninterruptible Power Supply, solar-powered, backup power, load wattage, run-time, renewable energy.*

## INTRODUCTION

Due to the steady increase in energy demand, the U.S. Energy Information Administration projected energy consumption to increase dramatically. An increase in the use of non-renewable energy resources will be observed to meet the energy demand.

According to the International Energy Agency, in 2021, 61.3% of global electricity came from combustible fossil fuels. Fossil fuels run out quickly, and their combustion contributes to the worldwide increase in temperature, air pollution, and the severing of the Ozone layer conditions (Nicoletti et al., 2014). Several studies have shown that the combustion of fossil fuels has negative impacts on health and the environment (Nicoletti et al., 2014; Suranovic, 2013; Rasoulinezhad et al., 2020). Inhalation of toxic emissions from the combustion of fossil fuels can cause harm to humans (Perera, 2017).

In the first quarter of 2019, only 26% of the world's electricity was generated using renewable energy resources (International Energy Agency, 2020). The rest of the electricity was sourced from non-renewable energy resources, mainly coal and other fossil fuels.

According to the 2019 Department of Energy of the Philippines report, 79.4% of the energy generated was collectively consumed by the residential, industrial, and commercial sectors. In the Luzon grid, 86% of the electricity was generated using non-renewable energy resources, namely, coal, natural gas, and oil (Department of Energy, 2019). In the same year, the maximum electricity demand was 11,344 MW. Meanwhile, the Visayas and Mindanao grids recorded an average maximum energy demand of 2100 MW.

In 2019, there were 186 yellow alerts (low supply of electricity) and 10 red alerts (insufficient supply of electricity) occurrences (Department of Energy, 2019). These incidents resulted in power outages and interruptions. Even with the aid of legislation like the

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R.A. 9136 or the Electric Power Industry Restructuring Act of 2001 (EPIRA), whose objective is to ensure the reliability and quality of electric power for the consumers, reduction of power outages and interruptions remains a challenging task, especially for some areas. In addition, the EPIRA law's objective is to ensure electricity affordability; however, this objective still needs to be fulfilled from the day of effectivity of this Act (Navarro et al., 2016).

It can be implied that electricity should be sourced from renewable energy resources. Solar energy is highly favorable among renewable energy resources and is progressively developing worldwide. In addition, solar energy is an excellent energy source since it is cheap, accessible, efficient, and can be sourced freely (Kannan & Vakeesan, 2016). Further, solar energy does not require enormous contraptions that need much maintenance. Also, it does not emit harmful fumes and noise to the environment. Furthermore, solar energy can be a reliable and steady source of electricity. Further, solar energy can function efficiently if placed in the proper orientation and location (Jawaid et al., 2012).

Nowadays, it is essential to have an uninterrupted power source to continuously energize the electronic devices used for online schooling or work from home. There should be an uninterrupted power supply for the internet modem as well.

To guarantee the best use and sustainability of the country's energy resources, Republic Act No.11285, also known as the "Energy Efficiency and Conservation Act," and Republic Act No. 9513, known as the "Renewable Energy Act of 2008," stimulate and promote the development of practical renewable energy technology and systems. Additionally, to successfully stop or lower hazardous emissions, balance economic development and expansion objectives, and preserve human health and the environment.

Energy storage equipment is essential since it resolves the weak nature of renewable energy, that is, intermittent. Energy storage equipment in a battery can store the energy for later use. Lithium-Iron Phosphate has better electrical performance among all the batteries today (W. Kurpiel, 2022).

With these, the researchers designed and developed a hybrid battery bank with a 100 AH (Amp-Hour) capacity called SOLUPS (Solar Powered Uninterruptible Power Supply). This can be used in energizing devices for productivity and essential AC-powered appliances. The battery bank comprises the hybrid charging module, the battery management system, and the batteries. The SOLUPS is designed to be capable of hybrid charging to ensure the reliability of the SOLUPS in terms of energy availability.

## OBJECTIVES OF THE STUDY

In this study, the researchers designed, developed, and evaluated the SOLUPS powered by solar energy and battery storage composed of lithium-iron-phosphate batteries. Shown in Figure 1 below is the input-process-output model of the study.

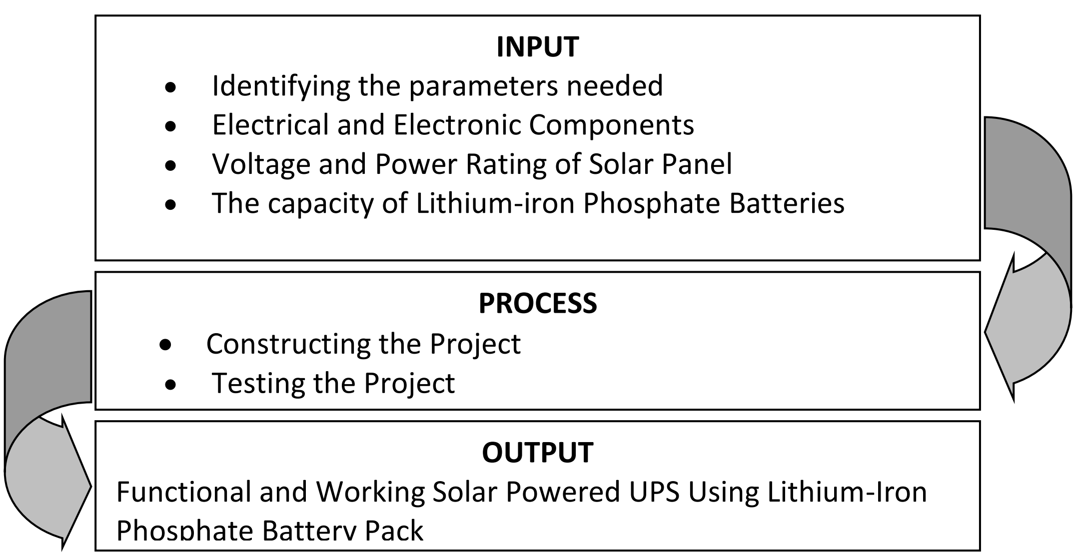


**Fig. 1.** *Paradigm of the study*

**Statement of the Problem**

Generally, this study aimed to create a solar-powered UPS that can serve as a backup power known as SOLUPS. Specifically, the study aimed to answer the following specific questions:

1. What design of SOLUPS can be used to power AC and DC devices?
2. What is the time that the SOLUPS require charging using:
   a. Solar energy (DC); and
   b. AC charging?
3. Is there a significant difference between the theoretical and actual charging time of the SOLUPS?
4. What is the run-time of the SOLUPS when powering;
   a. AC loads; and
   b. DC loads?
5. What variable (type of load, load wattage, and data type) significantly affects the run-time of the SOLUPS?
6. Is there a significant interaction between the load wattage and the type of load in terms of the run-time of the SOLUPS?
7. What economic factors can be considered in developing the SOLUPS?

**Hypotheses**

The following hypotheses were tested in their null form at a 5% significance level.

1. There is no significant difference between the theoretical and actual charging time of SOLUPS in terms of solar charging and AC charging.
2. The type of load, data type, and load wattage have no significant effect on the run-time of the SOLUPS.
3. There is no significant interaction between the type of load and the load wattage on the run-time of SOLUPS.

**Significance of the Study**

This research project aimed to address the issue of power outages and encourage the adoption of renewable energy, specifically solar power. Its significance extends to various stakeholders:

Community: The solar-powered uninterruptible power supply (SOLUPS) provides a reliable alternative power source during power interruptions, enhancing community resilience.

Environment: By utilizing renewable energy, the SOLUPS promotes environmental sustainability. It reduces reliance on fossil fuels, minimizing harmful emissions and noise pollution.

Researchers: The study provides valuable insights for Electrical Engineering students, enabling them to apply theoretical knowledge to real-world scenarios and gain a deeper understanding of electrical and electronic components.

Future Researchers: The project serves as a valuable reference for future researchers exploring the development and improvement of solar-powered UPS systems utilizing lithium-iron-phosphate batteries. It paves the way for further innovation in this field.

**Scope and Delimitation**

The study focused on the project's design, development, and operation. Additionally,

1. It dealt with developing the SOLUPS, a solar-powered UPS with a prismatic lithium-iron-phosphate battery pack.
2. It focused on harnessing renewable energy, which is solar energy. However, conventional AC outlets were used to test the hybrid charging capability of the SOLUPS. Other renewable energy sources with a DC output can charge the SOLUPS if their output is the same as that of the solar panel.
3. This research output can power AC electronic devices with a maximum collective load of 800 watts (40% loading of the inverter). The proposed usual load is only around 350W (17.5%) maximum, which means that 40% of the inverter is still enough to power the AC loads.
4. The project was developed and tested in Urdaneta City, Pangasinan. The testing of the SOLUPS ran for 15 days.

**Definition of Terms**

The following terms are defined operationally based on their use in the study.

Amp Hour (AH). This is a unit that indicates how many amperes are used every hour. This is the reference to identify which devices can be powered by the system.

Battery Pack. A battery pack is a set of any number of (preferably) identical batteries or individual battery cells. It is a connection of batteries in series and parallel. It was used to provide a higher voltage to the system.

Collective Load. This refers to the sum of load wattages on the AC output of the SOLUPS. The

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collective load for the SOLUPS must not exceed 800 watts.

Depth of Discharge (DOD). This refers to how much energy is cycled into and out of the battery on a given cycle. It is expressed as a percentage of the total capacity of the battery. This is the battery's capacity level wherein it has to be recharged to avoid damage to the battery.

Hybrid Charging. This is a method of charging devices in two ways. The SOLUPS was charged using solar panels (DC) and a conventional outlet (AC).

Lithium-iron phosphate. This is a type of battery that uses lithium as its component. This type of battery was used for more efficient service.

Prismatic. A type of battery that is in the form of a prism

Run-time. This refers to the time it took the fully charged SOLUPS to be drained from 13.6V to 12.6V under specific load wattage.

Solar Power. It is defined as using the sun as an energy source to produce electricity. In this research, solar power was the source of energy that was stored in the battery pack to power small electronic devices.

Uninterruptible Power Supply (UPS). It is a device that allows a computer to keep running for at least a short time when the primary power source is lost. It is also used to protect from power surges. In this project, UPS acted as a temporary power source for small electronic devices when a power interruption occurs and as an inverter of the whole system.

According to Lidula and Rajapakse, a UPS system resembles the concept of microgrids in academic literature, especially when paired with electrical-producing sources. A microgrid is a subset of a more extensive power system. It is a distribution system that can work independently, parallel to the grid, or transition between grid-connected and self-contained modes. The autonomous mode is also known as a manner of islanding.

There are three parts of a microgrid. Generation, storage, and load. Some studies additionally distinguish generation from grid-connected voltage source converters, which are utilized in DC microgrids to provide power to consumers to obtain energy from a linked AC grid (usually the utility grid). Distributed generation is a term used to describe energy generation sources in microgrids. In comparison to utility-scale power plants, their output power is minimal. For various reasons, renewable energy sources such as wind and solar PV have been identified as ideal for microgrids. Therefore, there has been a recent surge in academic interest in distributed generation and microgrids. Energy storage is utilized to keep the microgrid's power balance which helps to supply power during transitions between islanding and grid-connected mode, decreases the effects of transients, provides ride-through capabilities in the event of generation fluctuation, and helps to provide power during transitions between islanding and grid-connected mode. In theory, practically any energy-storage technology can be employed. However, batteries are ideal for microgrids, supercapacitors, and flywheels.

Comparing the Lithium Iron Phosphate and Lithium-Ion battery, some parameters are to be considered, like the energy level wherein the lithium-ion battery is higher at 150/200 Wh/kg compared to lithium iron phosphate with 90/120 Wh/kg. In terms of the life cycle, lithium iron phosphate has 1,000- 10,000 life cycles that can withstand high temperatures with small degradations, while lithium-ion has only a 500-1000 cycle life due to its high energy density, which makes the battery unstable in handling high temperatures. LiFePo4 can be stored with a 350-day shelf life, while lithium-ion can be stored with a 300-day shelf life. In terms of safety, LiFePo4 is safer than lithium-ion because LiFePo4 has excellent chemical stability and good performance on thermal; it is also incombustible when there is a short circuit as the phosphate does not explode when the battery is overcharged, while lithium-ion becomes unstable due to high energy density and can quickly heat (Manuel, 2021).

Compared to lead-acid battery, lithium iron phosphate is lightweight and has a longer life cycle compared to lead-acid that has only 500-900 times; it has 97% of conversion energy, while lead-acid has 80%; it does not contain heavy metals, rare metals, it is also non-toxic and no pollution compared to lead-acid that has heavy metals such as lead and antimony and causes pollution to the environment, it quickly leaks and can lead to battery corrosion and physical injuries. The LiFePo4 can be charged and discharged anytime; it can withstand a wide range of temperatures, unlike the lead-acid that freezes when the temperature is very low; it can also be a good battery because if there is substantial power, it can quickly charge, and release electricity (Grepow, 2019).

Compared to Nickel Cadmium, LiFePo4 has 95 % charge efficiency while NiCd has only 85%; it has 8-10 years of lifespan compared to the two batteries that have only 3-4 years, it also performs in high temperatures; unlike the two other that performs only up to 50 degrees

Celsius, and it does not produce pollutant unlike those two that contains high toxic, and has limited future uses (NVC lighting, 2022).

**Literature Review**

According to Mondol et al., when the DC input power from the PV system was less than the rate of the inverter capacity, the study found that inverter efficiency losses increased. The inverter's partial load operation, which led to significant energy loss, was the primary factor in its efficiency drop. This happened because the inverter model used some energy input to monitor the grid, track the MPP, and perform the initial auto-test activities. This inverter had a high minimum energy level at its rated capability. Since it needed more energy to start functioning, more energy was lost under low input circumstances. All energy losses that occur within the inverter are referred to as system losses. No converter can convert DC to AC with an efficiency of 100%. This shows that the AC energy output is less than the DC energy input. The efficiency of the inverter ranges typically from 95 to 98%. The efficiency can vary depending on the DC input power and voltage.

According to T. Bengtsson, H. Hult, a solar-powered UPS has two main components: a solar module with a solar cell that converts solar energy to electrical energy and an inverter that converts electrical energy into alternating current for usage in our houses. On the other hand, the UPS will serve as an inverter in this project. As a result, the loads will have constant access to electricity. A solar charge controller (SCC) and a battery are two other minor components of a solar-powered UPS. The SCC will keep the battery from overcharging by regulating it.

In evaluating the performance of the power supply, different reliability indices are used that focus on the power supply interruption or the availability of power supply to end-users. Some customer-oriented indices are the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). In this study, the adjusted annual SAIFI and SAIDI are determined by removing the significant event days and calamity days, and the value computed will be compared to the ERC standards.

De Leon et al. conducted a study entitled "Portable Solar Powered Generator," wherein they developed a Portable Solar Powered Generator as an alternative generating reserve supply. This project uses photovoltaic panels to capture solar energy from the sun and the storage system, which composes a LiFePo4 battery pack. Other components of the portable solar-powered generator include a 20 A MPPT charge controller, 500 W modified sine wave inverter, 80 A 4s BMS, DC breaker, DC voltmeter, AC voltmeter, and 12 V 30 A active relay. Once the energy has been gathered and converted into electrical energy, it can supply electricity to the consumers. Its advantage utilizes the use of renewable energy for it is cleaner to use compared to fuel-based generators like diesel and gasoline-powered generators. It is also economical and less expensive in terms of maintenance because it does not easily break. It does not also produce any noise during its operation. However, one disadvantage is that it relies on daylight; it requires higher costs during development and installation, and it is only appropriate to charge for small gadgets and appliances. Although it has limitations, it is still helpful at home during power interruptions because it will avoid delays with work. This project powers up WI-Fi routers, laptops, desktop lights, and fans. It is also not automatically connected to the grid; therefore, if there is an interruption, it requires manual switching; the researchers of this project conducted three tests; the first one is the loads being charged in the project, then the run-time as it discharges and the run-time as it charges. It has been found to supply power to mobile phones, desktops, laptops, electric fans, and light bulbs. It is also found that the lower the rating of loads, the longer the run time to discharge the battery. It is recommended by the researchers to use an MPPT solar charge controller, a Pure sine wave inverter to cater to higher loads, and an active balancer and wheels for the enclosure.

According to D. Rooij(2018), several factors can affect the battery's discharge rate, such as the rating of the connected load, operating temperature, and charging/ discharging cycle. The article also stated that when a load is connected to a battery, there is current drawn from the battery; the greater the current, the faster the battery discharges. When the battery supplies a high load wattage, the faster the battery discharges. If the battery exerted much work by supplying higher load wattage, the voltage and current being drawn are higher, and the power it supplies is also higher since the wattage, the current, and the voltage are proportional, which only means that the discharging rate is higher. When the battery is in idle mode, or when a load is still connected to the battery but no currents are drawn, it still discharges. It was discussed that the battery being used in the experiment has a stable, slowly discharging rate when the battery percentage is at 40-80%, but when it drops to 40% to 0%, the battery is discharging at an

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unstable rate and when it reaches this state the program in the inverter should disconnect all the loads connected to the battery.

Power interruptions are frequent in the Philippines; SAIDI scores may indicate that distribution utilities comply with the Energy Regulatory Commission (ERC) standards. An uninterruptible power source is essential since most of the devices used for productivity need electricity to run, especially for those in work-from-home settings or students conducting their classes online. A portable power supply can be reliable since it can be conveniently carried around to energize devices in far-flung areas. Battery banks can be used to create a portable power supply, and an inverter can be added so that the power supply can also power devices using alternating current (AC). Among battery types, lithium-iron-phosphate is the safest, most economical, and has a higher length of service. Lastly, electricity should be sourced from renewable energy sources since it is environmentally friendly and more economical in the long run. Moreover, among renewable energy sources, solar power is the most viable since it is free and can be easily sourced.

## MATERIALS AND METHODS

### Research Design

In this study, the researchers used descriptive and developmental research methods. The researchers used the developmental research method to develop the SOLUPS. The descriptive research method was used to describe the attributes and behavior of the SOLUPS accurately and systematically.

### Statistical Treatment

To characterize the charging time of the system, the arithmetic mean was used. Paired Sample T-test was also used to analyze if there is a significant difference between the theoretical and actual charging time of the SOLUPS. Also, to determine the impact of load wattage and type of load as well as to determine what variables have a significant effect on the run-time of the SOLUPS, Analysis of Variance (ANOVA) was used. In addition, Scheffe's Test was conducted to compare the means of the variables.

## RESULTS AND DISCUSSION

### Design of SOLUPS

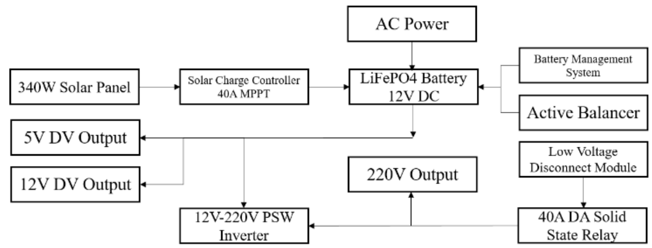


Fig. 2. Block Diagram of SOLUPS

The researchers designed the SOLUPS to store the solar energy harnessed from the sun. Harnessing the solar energy from the sun is done thru a 340W monocrystalline solar panel. The harvested energy is then transmitted to the 40A Maximum Power Point Tracking (MPPT) solar charge controller, which maximizes the energy harvested from the solar panel and regulates the voltage and current for the battery assembly. The solar charge controller used in this project can use up to a maximum of 550W solar panels.

The battery assembly uses three significant components: Lithium-Iron Phosphate (LiFePO4) prismatic cells, a battery management system, and a capacitive balancer. Four units of 3.2V, 100AH LiFePO4 are used and arranged in a series configuration. This configuration resulted in a 12.8V system with a total capacity of 1280Wh. The 100A battery management system is added to regulate the battery's charging and discharging, which helps it maximize its life cycle. Additionally, a 5A capacitive active balancer is added to equalize the voltage across each LiFePO4 cell to maintain the overall battery health and performance (De Leon et al., 2020)

The output battery output has two paths, one for the DC load and one for the AC load. The DC load side is composed of 2-12V outlets and 2-5V outlets. On the other hand, the AC load side comprises a 2000W 12VDC-230VAC inverter protected using circuit breakers. However, 40% (800W) of the inverter rating will be its maximum load, so the inverter will not overheat or overload.

A 40A DC-AC solid state relay (SSR) is added to the system to automatically switch off the AC output when the battery's voltage is low (12.6V). This ensures that the battery will not be drained or used below is suggested DOD level (12.6V or 15%). The researchers integrated the SSR with a low-voltage disconnect module.

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Lastly, an added feature of AC charging is added to the SOLUPS to ensure the availability of stored electricity. This feature allows the SOLUPS to be charged when the harvest using solar panels is insufficient. See Appendix B, G, and H.

Considering that the SOLUPS is relatively tiny compared to the wall-mounted setups, it gives ease to the users. Further, all of the components of the SOLUPS are contained inside the enclosure, making transporting it effortless. Furthermore, small setups like the SOLUPS can be easily stored when not in use.

Table 1. Tabulation of Materials

| Particulars | Description | Quantity |
|---|---|---|
| Battery | 3.2V,100AH Prismatic LiFePO4 | 4 pcs |
| Battery Management System (BMS) | 4S 12V, 100A for LiFePO4 | 1 pc |
| Solar Charge Controller (SCC) | 40A Maximum Power Point Tracking (MPPT) | 1 pc |
| Inverter | 2000W Pure Sine Wave | 1 pc |
| DC Miniature Circuit Breaker (MCB) | 32A | 1 pc |
| DC Miniature Circuit Breaker (MCB) | 63A | 1 pc |
| AC Miniature Circuit Breaker (MCB) | 10A | 1 pc |
| Digital Voltmeter-Ammeter | DC 0-200 Part Zone Expansion Module (PZEM) | 1 pc |
| AC Charger | 14.8V, 5A Li-ion PO4 | 1 pc |
| Active Balancer | 4S | 1 pc |
| Low Voltage Disconnect (LVD) Module | HCW-M635 | 1 pc |
| Solid State Relay | 40A DA | 1 pc |
| Surge Protective Device (SPD) | 500V DC | 1 pc |
| Wattmeter | 4 in 1 | 1 pc |
| Exhaust Fan | 12V DC | 1 pc |
| Connector | 12V DC Jack | 4 pcs |
| Connector | XT90 | 1 pc |
| Connector | XT60 | 4 pcs |
| AC Power Cable | 3P IEC 320 C14 Male + Female 2-pin Plug | 1 pc |
| Buck Converter | 3-32V DC, 6A | 1 pc |
| Electrical Wire | 4mm.$^2$ PV Wire | 8 meters |
| Electrical Wire | 6mm.$^2$ DC Cable | 3 meters |
| Electrical Wire | 2.0mm.$^2$ AC Cable | 4 meters |
| Electrical Wire | #18 AWG Stranded Wire | 2 meters |
| USB Hub | 5V Round | 1 pc |
| Switch | 220V, 5A Round Rocker | 4 pcs |
| in-line fuse | 15A, 30A Blade Type | 2 pcs |

**Output Power of SOLUPS**

The SOLUPS' battery has a total energy of 1280Wh, meaning it can deliver 1280W of power for one hour. The researchers used a 2000W pure sine wave inverter; in this way, the inverter will not experience overloading since the maximum that SOLUPS is rated to deliver is 1200W only. Moreover, the maximum use of the inverter will only be at 40% (800W) of its total capacity. Moreover, the suggested AC load for a residential setting is only 350W, or 17.5% of the total capacity of the inverter. Compared to the solar-powered generator of De Leon et al. in 2020, the SOLUPS can supply AC power up to 800W. Compared to commercially available portable electric generators, SOLUPS can power more devices.

**Solar Charging of SOLUPS**

Table 2. Theoretical vs. Actual Solar Charging

| AVERAGE SOLAR CHARGING | | |
|---|---|---|
| Hour | **Theoretical WH** | **Average WH** |
| **1** | 256 | 208.67 |
| **2** | 512 | 409.67 |
| **3** | 768 | 599.33 |
| **4** | 1024 | 796.00 |
| **5** | 1280 | 994.00 |
| **6** | 1536 | 1178.33 |
| **7** | 1792 | 1360.33 |

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Table 2 shows the average watt-hour per hour harvested using solar charging from 3 trials. The peak sunlight in Urdaneta City, Pangasinan is 5 hours (9 am to 2 pm); however, it took 7 hours for SOLUPs to be fully charged at 1360Wh. See Appendices D and E. The actual watt-hour harvested is lesser than the theoretical watt-hour due to the solar panel's efficiency and the solar charge controller. Moreover, the weather could be more consistent, thus affecting solar energy harvest (S. Ghazi & Ip, 2014).

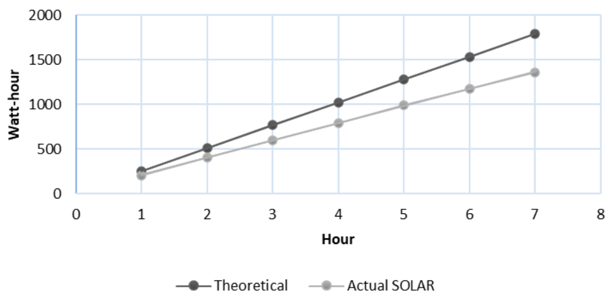


Fig. 3. Theoretical vs. Actual Solar Charging Time of the SOLUPS

## AC Charging of SOLUPS

Table 3. Theoretical vs. Actual AC Charging

| AVERAGE AC CHARGING | | |
|---|---|---|
| **Hour** | **Theoretical WH** | **Average WH** |
| **1** | 71 | 63.67 |
| **2** | 142 | 132.67 |
| **3** | 213 | 200.67 |
| **4** | 284 | 263.67 |
| **5** | 355 | 334.33 |
| **6** | 426 | 402.67 |
| **7** | 497 | 470.33 |
| **8** | 568 | 539.00 |
| **9** | 639 | 606.33 |
| **10** | 710 | 675.33 |
| **11** | 781 | 746.00 |
| **12** | 852 | 812.67 |
| **13** | 923 | 882.67 |
| **14** | 994 | 948.33 |
| **15** | 1065 | 1016.00 |
| **16** | 1136 | 1086.00 |
| **17** | 1207 | 1154.00 |
| **18** | 1278 | 1222.00 |
| **19** | 1349 | 1289.67 |

Table 3 shows the average watt-hour per hour accumulated using AC charging from 3 trials. The AC charging of SOLUPS takes 19 hours to be fully charged at 1289.67Wh. Theoretically, the SOLUPS will be fully charged at the 18th hour, but because of the losses, it took 19 hours.

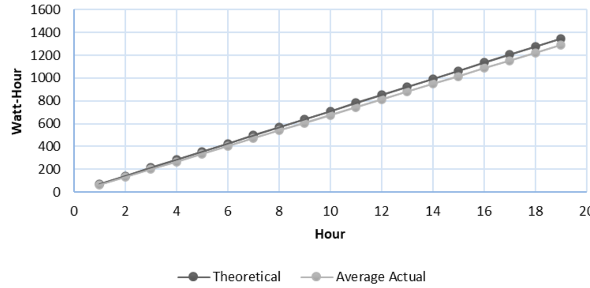


Fig 4. Theoretical vs. Actual AC Charging Time of the SOLUPS

## Solar Charging

Table 4. Solar Charging Paired Samples T-Test

| | | | statistic | df | p |
|---|---|---|---|---|---|
| Actual | Theoretical | Student's t | -4.45 | 6.00 | 0.004 |

The Paired Sample T-test revealed a significant difference between the theoretical and actual charging time of SOLUPS using solar energy ($p=0.004 < p=0.05$). Again, the actual watt-hour harvested is lesser compared to the theoretical watt-hour due to the efficiency of the solar panel and the solar charge controller. Additionally, the weather could be more consistent, thus affecting solar energy harvest (S. Ghazi & Ip, 2014).

## AC Charging

| | | | **statistic** | **df** | **p** |
|---|---|---|---|---|---|
| Actual | Theoretical | Student's t | -9.32 | 18.0 | < .001 |

The Paired Sample T-test revealed a significant difference between the theoretical and actual charging time of SOLUPS using AC charging ($p<0.001 < p=0.05$). Due to the efficiency of the AC charger and voltage drops, the actual value deviated from the theoretical value.

## Average Run-Time

Table 6. Run-Time of Connected Loads at Specified Wattages

| Type of Load | Load Wattage (W) | Average Actual Run-Time (Hours) |
|---|---|---|
| **AC** | 350 | 3.25 |
| | 200 | 5.30 |
| **DC** | 350 | 3.38 |
| | 200 | 5.47 |

Table 6 shows the average run-time of SOLUPS across different load wattages and types of load from 3 trials. The table reveals that the 200W AC load recorded

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the most extended average actual run-time of 5.47 hours, while the 350W AC load recorded the shortest average actual run-time of 3.25 hours. Thus, it can be inferred that the higher the load wattage, the shorter the run time will be (D. Rooij, 2018).

**Comparison of Parameters**

Table 7. Comparison Across the Parameters of SOLUPS

| | Sum of Squares | Df | Mean Square | F | p |
|---|---|---|---|---|---|
| Load Wattage | 33.4662 | 1 | 33.4662 | 875.64375 | < .001 |
| Type of Load | 0.0494 | 1 | 0.0494 | 1.29186 | 0.271 |
| Data Type | 2.7512 | 1 | 2.7512 | 71.98403 | < .001 |
| Load Wattage ✻ Type of Load | 3.71e-4 | 1 | 3.71e-4 | 0.00971 | 0.923 |
| Residuals | 0.6879 | 18 | 0.0382 | | |

ANOVA results show sufficient evidence to say that at least one Load-wattage significantly affects the run-time of SOLUPS ($p<0.001 < p=0.05$). This means that the load wattage of 200W or 350W will affect the run-time of the SOLUPS. Further, the table reveals that the Type of Load has no significant effect on the run-time of the SOLUPS ($p=0.271 > p=0.05$). Thus, the DC and AC types of loads will not significantly affect the run-time of SOLUPS. Furthermore, the table shows that the Data Type has a significant effect on the run-time of the SOLUPS ($p<0.001 < p=0.05$). Hence, there is a considerable difference between the theoretical and actual run-time of the SOLUPS. The difference between the theoretical and actual run-time values is due to the efficiency of the equipment used. Moreover, the ANOVA revealed no significant interaction between the Type of Load and Load Wattage ($p=0.923 > p=0.05$). This means that the change in the run-time of SOLUPS considering the Type of Load and Load Wattage has no notable difference.

Table 8. Post Hoc Comparison on Load Wattage

| Comparison | | | | | | | |
|---|---|---|---|---|---|---|---|
| Load Wattage | | Load Wattage | Mean Difference | SE | df | t | $p_{scheffe}$ |
| 200 | - | 350 | 2.42 | 0.0819 | 18.0 | 29.6 | < .001 |

Since the ANOVA results show a significant difference in the run time in terms of load wattage, a post hoc analysis was conducted to determine which load wattage delivers a longer run time. Results of Scheffe's test indicate that a load wattage of 200 will have an average advantage of 2.41 hours of run-time compared to 350 load wattage. Thus, using 200 load wattage will maximize the run time of SOLUPS.

Table 9. Post Hoc Comparison on Type of Load

| Comparison | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type of Load | | Type of Load | Mean Difference | SE | df | t | $p_{scheffe}$ |
| AC | - | DC | -0.0931 | 0.0819 | 18.0 | -1.14 | 0.271 |

The ANOVA results further revealed a significant difference in the run time in data type; a post hoc analysis was conducted to determine which type of load delivers a longer run time. Results of Scheffe's test indicate that the AC type of load has an average disadvantage of 0.0931 hours run-time compared to the DC type of load. Thus, using DC-type loads will maximize the run time of SOLUPS. This is because the DC output is directly sourced from the battery instead of the AC output, which runs through the inverter, solid state relay, and the watt-meter, thus, incurring more loss than the DC output (Mondol et al.).

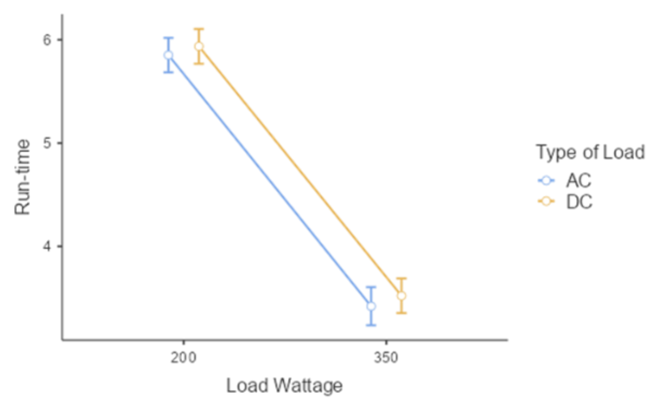


Fig. 5. Estimated Marginal Means of the Load Wattage and Type of Load

Figure 5 further reveals that the 200W load wattage is advantageous compared to the 350W load wattage. Furthermore, DC-type loads allow the SOLUPS to have a longer run time. Again, this is because the DC output is directly sourced from the battery instead of the AC output, which runs through the inverter, solid state relay, and the watt-meter, thus, incurring more loss than the DC output (Mondol et al.).

**Simple Effect of Type of Load**

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Table 10. Effect Considering Type of Loads

| Type of Load | Simple Effect of Type of Load |
|---|---|
| A3T-D3T | 0.00 |
| A3A-D3A | -0.14 |
| A2T-D2T | 0.00 |
| A2A-D2A | -0.17 |

*Legend:*
*A-AC D-DC 3-350 2-200 T-Theoretical A-Actual*

Table 10 shows that the theoretical run-time of SOLUPS with 350W load is expected to decrease by 0 hours if AC loads are used instead of DC loads. Further, the actual run-time of SOLUPS with 350W load is expected to decrease by 0.14 hours if AC loads are used instead of DC loads. Furthermore, the theoretical run-time of SOLUPS with a 200W load is expected to decrease by 0 hours if AC loads are used instead of DC loads. Lastly, the actual run-time of solups with 200W load is expected to decrease by 0.17 if AC loads are used instead of DC loads. This means that the 200W DC load can achieve a longer run-time among all the combinations.

**Simple Effect of Load Wattage**

Table 11. Effect Considering Load Wattage

| Load Wattage | Simple Effect of Load Wattage |
|---|---|
| A3A-A2A | -2.06 |
| A3T-A2T | -2.74 |
| D3A-D2A | -2.09 |
| D3T-D2T | -2.74 |

*Legend:*
*A-AC D-DC 3-350 2-200 T-Theoretical A-Actual*

Table 11 shows that the actual run-time of SOLUPS is expected to decrease by 2.06 hours if the 350W AC load is used instead of the 200W AC load. Also, the theoretical run-time of SOLUPS is expected to decrease by 2.74 hours if the 350W AC load is used instead of the 200W AC load. Additionally, the actual run-time of SOLUPS is expected to decrease by 2.09 hours if the 350W AC load is used instead of the 200W AC load. Further, the actual run-time of SOLUPS is expected to decrease by 2.74 hours if the 350W AC load is used instead of the 200W AC load.

**Simple Effect of Data Type**

Table 12. Effect Considering Data Type

| Load Wattage | Simple Effect of Data Type |
|---|---|
| A3A-A3T | -0.41 |
| A2A-A2T | -1.10 |
| D3A-D3T | -0.28 |
| D2A-D2T | -0.93 |

*Legend:*
*A-AC D-DC 3-350 2-200 T-Theoretical A-Actual*

Table 12 shows that the run-time of SOLUPS with a 350W AC load is expected to decrease by 0.41 hours when the actual run-time is compared to the theoretical run-time. Further, the run-time of SOLUPS with a 200W AC load is expected to decrease by 1.10 hours when the actual run-time is compared to the theoretical run-time. Furthermore, the run-time of SOLUPS with a 350W DC load is expected to decrease by 0.28 hours when the actual run-time is compared to the theoretical run-time. Lastly, the run-time of SOLUPS with a 200W DC load is expected to decrease by 0.93 hours when the actual run-time is compared to the theoretical run-time.

**Main Effect on Run-Time**

Table 13. Main Effect on Run-Time in Three Parameters

| Main Effect | Main Effect on Run-time |
|---|---|
| Type of Load | -0.08 |
| Load Wattage | -2.41 |
| Data Type | -0.68 |

Table 13 shows that the run-time of SOLUPS decreases by 0.08 hours when AC loads are used instead of DC loads. Thus, using DC loads is better than using AC loads. However, the mean difference is statistically tiny, so both AC and DC loads can be used with an insignificant difference in the run-time. Additionally, the run-time of SOLUPS decreases by 2.41 hours when 350W loads are used instead of DC loads. It can be inferred that using a 200W load can prolong the run-time of SOLUPS compared to a 350W load. Moreover, the run-time of SOLUPS is expected to decrease by 0.68 hours when the theoretical run-time is compared with the actual run-time.

**Economic Analysis**

Table 14. Economic Parameters of SOLUPS

| Economic Parameters | |
|---|---|
| Total Mat Expenditures | ₱ 27,901.00 |
| Total Misc. Expenses | ₱ 1,861.00 |
| Rate of Return (ROR) | 5.5% |
| Cost-Benefit Ratio | 1.14 |
| Payback Period | 7.02 yrs |
| Return on Investment | 17.60% |

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The researchers also analyzed the economic factors of the SOLUPS. Calculations show that the ROR is 5.5%, meaning that SOLUPS is feasible and profitable. Further, the Cost-Benefit Ratio of SOLUPS is 1.14, which indicates that SOLUPS is cost-effective. Furthermore, the calculations suggest that the payback period of SOLUPS is 7.02 years. However, the battery of the SOLUPS is suggested to be maintained every 2000 cycles. Moreover, considering the profits, costs, and expenses of selling the SOLUPS, the annual return on investment is 17.60%.

Table 15. Cost of Charging

| Type of Charging | Estimated Cost |
|---|---|
| **Solar Charging** | ₱ 0.00 |
| **AC Charging** | ₱ 19.04 |

Table 15 shows the estimated cost of charging SOLUPS. Considering that the cost of solar energy harvest is free, the cost of solar charging is ₱ 0.00. Further, considering the cost of electricity for residential consumers served by PANELCO, the cost of charging the SOLUPS using AC charging is ₱ 19.04. It can be inferred that charging the SOLUPS using solar energy is better since it is free (Kannan & Vakeesan, 2016).

**Summary**

The primary goal of this study is to design and develop a hybrid battery bank with a 100 AH capacity called SOLUPS (Solar Powered Uninterruptible Power Supply). This can be used in energizing devices for productivity and essential AC-powered appliances. The SOLUPS could alleviate the problem of power outages and promote the utilization of renewable energy through solar energy. An AC-charging function is incorporated in the design to charge the SOLUPS whenever the solar energy harvest is insufficient.

Findings show that the charging time of SOLUPS would take 7 hours via solar charging and 19 hours via AC charging. Further, the 200W DC load recorded the most extended run-time of SOLUPS with 5.47 hours, while the 350W AC load recorded the shortest run-time with 3.25 hours. Among the variables, load wattage and data type significantly affected the run-time of SOLUPS. The 200W load wattage has a 2.41-hour advantage over the 350W load wattage. In addition, the DC loads have an average advantage of 0.0931 hours over AC loads. Furthermore, the SOLUPS is economical, with an ROR of 17.60%.

## Conclusion and Recommendation

Based on the findings, the researchers concluded the following:

1. Both AC and DC types of loads can be powered using the SOLUPS.
2. The SOLUPS requires 7 hours to be fully charged via solar power and 19 hours via AC c harging.
3. There is a significant difference between the theoretical and actual data due to the efficiency of the equipment used in the development of SOLUPS.
4. The average run-time of SOLUPS is 5.47 hours using 200W DC loads and 3.25 hours using 350W AC loads.
5. The 200W load will have an average advantage of 2.41 hours of run-time compared to the 350W load.
6. There is no interaction between the load wattage and the type of load in terms of the run-time of the SOLUPS.
7. Considering the economic factors, the SOLUPS is considered to be economical.

Recommendations

With the conclusions, the researchers recommend the following:

1. A power quality assessment should be done on the output of the SOLUPS to determine if factors can affect the output of SOLUPS.
2. Increase the wattage of the integrated AC charging of the SOLUPS to speed up the total time when the AC charging function is used.
3. Consider equipment or parts with higher efficiency in developing a solar generator to minimize losses.
4. Use other/ better inverter brands to prolong AC load battery run-time.
5. Use loads between 200-300W for an efficient run-time.
6. Mixed AC and DC loads with a collective wattage of 200W and 350W can be used.
7. To boost the profitability and marketability of the SOLUPS, look at alternatives that are just as effective or even better in terms of quality and cost.
8. Test the performance of SOLUPS considering the ambient temperature.
9. Use smart BMS to monitor battery voltage and harvest remotely via a smartphone application.
10. An internal temperature system can be integrated in the SOLUPS to keep track of the system's temperature.

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