JOURNAL OF SCIENCE, TECHNOLOGY AND ENGINEERING RESEARCH
Bilim, Teknoloji ve Mühendislik Araştırmaları Dergisi
ISSN (Online) 2717-8404
Available *online* at https://dergipark.org.tr/en/pub/jster

RESEARCH ARTICLE

Enhancing the Productivity of Bifacial Solar Panel System: The Impact of Battery Integration and Hybrid Inverter on Energy Cost Reduction

[*] Lloyd Russel P. Zabala, [1]Justin John Alce, [2]Allen M. Castidades, [3]Chandrei E. Celso, [4]Jhimuel S. Evaristo and [5]Edgardo M. Santos

[*1,2,3,4,5] Don Honorio Ventura State University, Electrical Engineering Department, Pampanga, Philippines
http://www.dhvsu.edu.ph/, Orcid. 0009-0002-1855-5189

Citation:
Zabala, L.R., Alce, J.J.,Castidades, A.M., Celso, C.E., Evaristo, J.S, Santos, E.M. (2025). *Enhancing the Productivity of Bifacial Solar Panel System: The Impact of Battery Integration and Hybrid Inverter on Energy Cost Reduction,* Journal of Science Technology and Engineering Research, 6(2): 78-92. DOI: 10.53525/jster.1725317

HIGHLIGHTS

- *Study on how battery integration made the solar panel more effecient and effective*
- *Battery can help the solar panel to be more productive and limit the excess*
- *The battery has great impact on the consumer's consumption and in cost reduction in billing*
- *In the analysis, integration of battery made the ROI and Payback period in the consumer came early than the expected time.*

Article Info

Received **:** June 23, 2025
Accepted **:** October 2, 2025

DOI:
10.53525/jster.1725317

***Corresponding Author:**
Lloyd Russel Zabala
2021313991@dhvsu.edu.ph
Phone: +639 977000621

ABSTRACT

Solar panels, also referred to as photovoltaic solar panels, can now be used by every consumer and distribution company to help keep up with the fast demand for electricity. Where to introduce the solar panel: An alternative way to mitigate the rise in electricity consumption is for the researchers to provide the answer that is in the solar panel introduction. It was improved and improved over the years until another company used other materials to make power. This study addresses the installation of 1-150Ah battery in 10- 565W Bifacial Monocrystalline Photovoltaic solar module installed in Santo. Nino Candaba, Pampanga, in terms of energy saving, solar energy harvesting efficiency, and return-on-investment period. The study will be monitored daily (5:00 am – 5:00 pm) to determine the effect of the installed battery. The result demonstrates that the implementation of a battery in four months. It can also offer benefits to the home and the utility to store and reduce electricity bill. Therefore, the battery installation shouldn't be for the show so that the solar panel can be used more effectively and efficiently. They thus make it possible to stock energy created in the bright sun for use at night or when demand for power is high. Hence, optimal incorporation of battery systems not only increases the efficiency of the whole solar energy system but also encourages more energy self-sufficient use.

Keywords: *Bifacial Solar Panel, Hybrid Inverter, Battery, Limiter*

I. INTRODUCTION

Electricity is a vital part of our daily routine and allows us to accomplish everyday tasks and to enjoy our lives in ways that many of our ancestors would never have considered. While the world is in development, electricity is obviously indispensable to our modern life. Yet escalating electricity prices are a global issue. Rapidly increasing use of electricity presents serious environmental, economic, and social problems Power plants like coal-fired power plants, geothermal power, etc., are the primary source of electricity throughout the world. Those power plants use fossil fuels (oil, coal, and gas) to generate electricity, but in some instances fossil fuels are decreasing because of overuse. Moreover, the power plant also has a significant role in increasing the possibility of having climate change (greenhouse gas emissions, water and air pollution). In the Philippines, the electricity used is from fossil fuels, which was 78%. [1] For those problems, there is an alternative solution known as renewable energy that consists of solar, wind, hydro, and geothermal. Solar power is widely considered to be one of the most efficient forms of power generation because solar energy is clean and renewable, emits no greenhouse gases, and is available to practically anyone on earth. [7]

A bifacial PV solar panel developed with both sides can capture the sunlight. This is useful in places with high ground reflectivity or in places with specially designed ground covers to increase reflectivity. The development of bifacial PV modules is more than an incremental improvement of solar technology; it is a true example of a shift in solar energy harvesting. [3] While monofacial systems are restricted to one-sided light exposure, the further developed bifacial systems exploit all available solar irradiance. This is made possible by improved cell and panel designs that use sophisticated geometry to capture light from different directions. The increase in energy production per unit area is highly valuable and enhances the overall efficiency of solar installations. [28]

Through the emerging development of solar panels that has been a great help to consumers and utilities, they introduced the use of batteries. The use of a battery is to store the excess energy that the solar panel generated and automatically operate when the power outage occurs. There are two types of batteries that are mainly used: lead-acid batteries and lithium-ion batteries. Between the types of batteries mentioned, the lithium-ion battery has more lifespan and efficiency than the lead-acid battery. Lithium-ion batteries may be more expensive, but they can last around 15 to 20 years and can operate at an efficiency of 70% to 80%. [29]

Solar energy systems are emerging as the top alternative to traditional power plants [2]. The system consists of solar panels, an inverter, and a battery; sometimes limiters are also involved to generate sunlight into electricity. Solar panels capture the solar energy. The inverter converts the direct current into alternating current. Lastly, the battery is the one that stores the excess electricity generated by the solar panel. In some instances, the limiter is placed to sell the excess electricity in the utility that the battery cannot handle or the batteries are already full [17]. Philippine government promoting solar energy and making significant investments in renewables, these panels are becoming increasingly appealing for large solar farms, homes, and rooftops [4].

This study evaluates the capability of bifacial solar panel in terms of productivity, efficiency and the year that the initial investment will return. Currently, the setup features a Deye hybrid inverter (5 kW– 6.5 kW), Ja solar panels with blue bifacial technology at 565 watts (10 panels), One Changhong 150 Ah battery and Limiter (5kW). This study aims to enhance the existing configuration by evaluating the performance of bifacial solar panels within a hybrid energy system and proposing the installation of a 150 Ah battery. This new setup is intended to boost energy storage capacity, allowing for the efficient capture and use of generated electricity. By storing any excess energy, it ensures that no electricity goes to waste, thereby optimizing the system's overall performance and promoting sustainability. Furthermore, this study looks into how the installation of a 5.65 kilowatt peak photovoltaic panel with a limiter and a 150 Ah lithium-ion hybrid system impacts the kilowatt-hour bill. The insights gained from this research are essential for guiding future investments in solar energy and play a significant role in enhancing the long-term sustainability of residential energy solutions.

With this, the objective of this study was to evaluate the performance and economic impacts of an enhanced hybrid energy setup, including bi-facial PV panel, inverter, limiter, and lithium-ion battery storage, within the context of residential energy consumption profile in the Philippines.
The specific objectives are:

- What is the performance in terms of kW production of bi-facial PV panel when connected using?
  1. A limiter system
  2. A hybrid setup (including battery)
- What is the energy profile of the customer in terms of?
  1. Monthly kWh billing?
  2. Energy loading and consumption patterns (daily and monthly usage)?
- What are the impacts of PV installation on the energy consumption and cost of the customer in terms of?
  1. Monthly kWh savings?
  2. Economic benefits, including the return on investment (ROI) and payback period?

However, this study had several limitations. The result is only depending on the performance of bi- facial monocrystalline solar panel with installed 1-150 lithium ion battery only in the system. The historical data may change depends on the month of evaluating and analyzing the production, when it is summer, rainy days or normal high of temperature. Additionally, the data gathered are in within 4 months only but the researcher ask the residence for the 2023-2024 electricity billing information for further analysis of the research.

II. METHOD

This research adopted a quantitative methodology to assess the effect of the hybrid solar system on reducing overall energy expenses. To specify, researchers will determine the ROI and payback period of both hybrid solar setups and solar setups. Researchers collected the data for the study over a four months' duration (January – April 2025). These data included monthly electricity bills provided by the system owner, which offered a clear comparison of energy consumption and cost before and after the installation of the hybrid solar setup. In addition to the billing data, researchers utilized the Solarman Business application, a digital platform designed to monitor and manage solar energy systems. This application played a vital role in supplying real-time data on the performance of both the solar panels and the integrated battery storage system. Through this platform, the researchers were able to track the monthly kilowatt-hour (kWh) usage, the energy generation capacity of the hybrid solar panels, and the efficiency and storage performance of the battery. Altogether, these data points allowed for a comprehensive analysis of the hybrid solar system's operational effectiveness and its impact on reducing the owner's electricity costs over time.

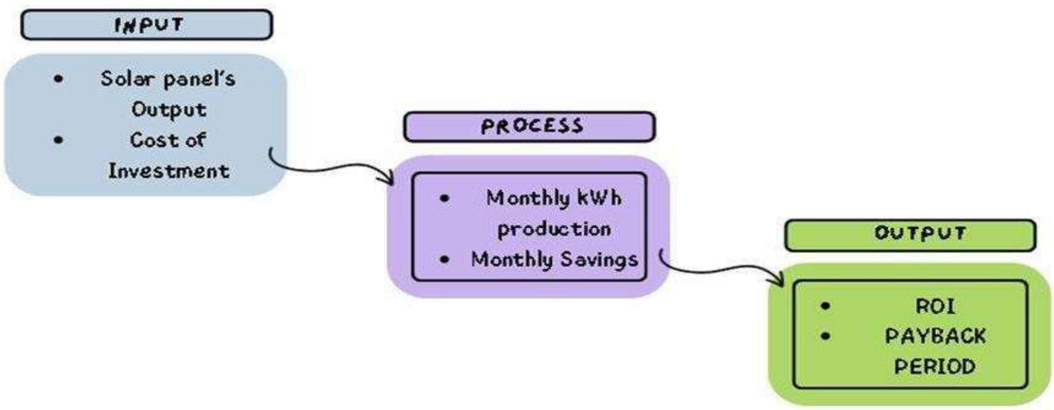

Figure 1. Input Process Output

Return on Investment (ROI)

The monthly savings were calculated based on the amount of energy generated by the solar panels and the energy discharged from the battery (Battery discharge is included for Hybrid solar set-up). The monthly Savings provided a foundation for estimating the return on investment (ROI) of the hybrid solar setup and solar set-up using the formula:

$$ROI\ (\%) = \frac{\text{Net Savings}}{\text{Cost of Investment}} \times 100$$

Payback Period

The payback period is the time (generally in years) in which return is required from investment or the amount of time it takes for the positive cash flow to exceed the initial investment, without concern for the time value of money. Using the formula:

$$\textit{Payback Period} = \frac{\textit{Cost of Investment}}{\textit{Net Savings}}$$

III. MATERIALS AND DIAGRAM

Solarman Business

Data are being collected through an application to determine the differences between the solar panel with and without a battery. The application provides specific information necessary to achieve the study's goal, including daily and monthly production, consumption, and excess energy from the battery. Figure 2. is the interference of the application.

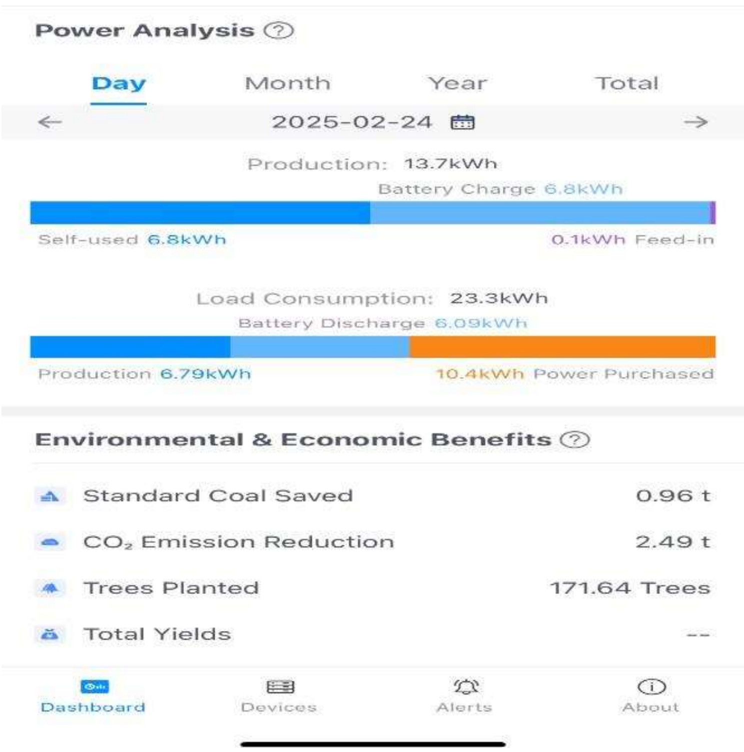

Figure 2. Solarman business

Load Schedule

Table 1. Shows all the running appliances throughout the household in this study.

CIRCUIT NO.	NO. OF LOADS	VOLT-AMPERE	LOAD DESCRIPTION	VOLTS	AB	BC	CA	3P	PROTECTION	SIZE OF WIRE AND CONDUIT
1	8	800	LIGHTING @100W	230	3.478				20	2-3.5mm^2 THHN Cu + 1-2.0mm^2 (G) 20mm RSC/MC
2	15	1500	LIGHTING @100W	230	6.522				20	2-3.5mm^2 THHN Cu + 1-2.0mm^2 (G) 20mm RSC/MC
3	10	1800	C. OUTLET	230	7.826				20	2-3.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
4	7	1260	C. OUTLET	230	5.478				20	2-3.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
5	1	500	WASHING MACHINE	230	2.174				20	2-3.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
6	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
7	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
8	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
9	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
10	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
11	1	2300	A.C.U @1.5HP	230	10				30	2-5.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
12	1	1840	JETMATIC @1HP	230	8				30	2-3.5mm^2 THHN Cu + 1-2.0mm^2 (G) 20mm RSC/MC
13	1	500	REFRIGERATOR	230	2.174				20	2-3.5mm^2 THHN Cu + 1-3.5mm^2 (G) 20mm RSC/MC
14	1	1200	SPARE	230	5.217				30	2-3.5mm^2 THHN Cu + 1-2.0mm^2 (G) 20mm RSC/MC
TOTAL		23200			100.87					
COMPUTATION: IT = (100.87)(80% DF) + (10 x 0.25) = 83.20 AMPERE										
COMPUTATION: Imcb = (100.87)(80% DF) + (10 x 1.25) = 93.20 AMPERE										
MAIN PROTECTION: 100 AT, 100 AF, 3POLE IN NEMA 1 ENCLOSE @90 degrees										
MAIN FEEDER: 2-30 mm^2 THHN WIRE + 1-14 mm^2 THW WIRE (EGC) in 32mmØ RSC @90 degrees										
GROUND ELECTRODE CONDUCTOR: 8.0mm^2 TW Cu.WIRE (GEC)										

Schematic Diagram

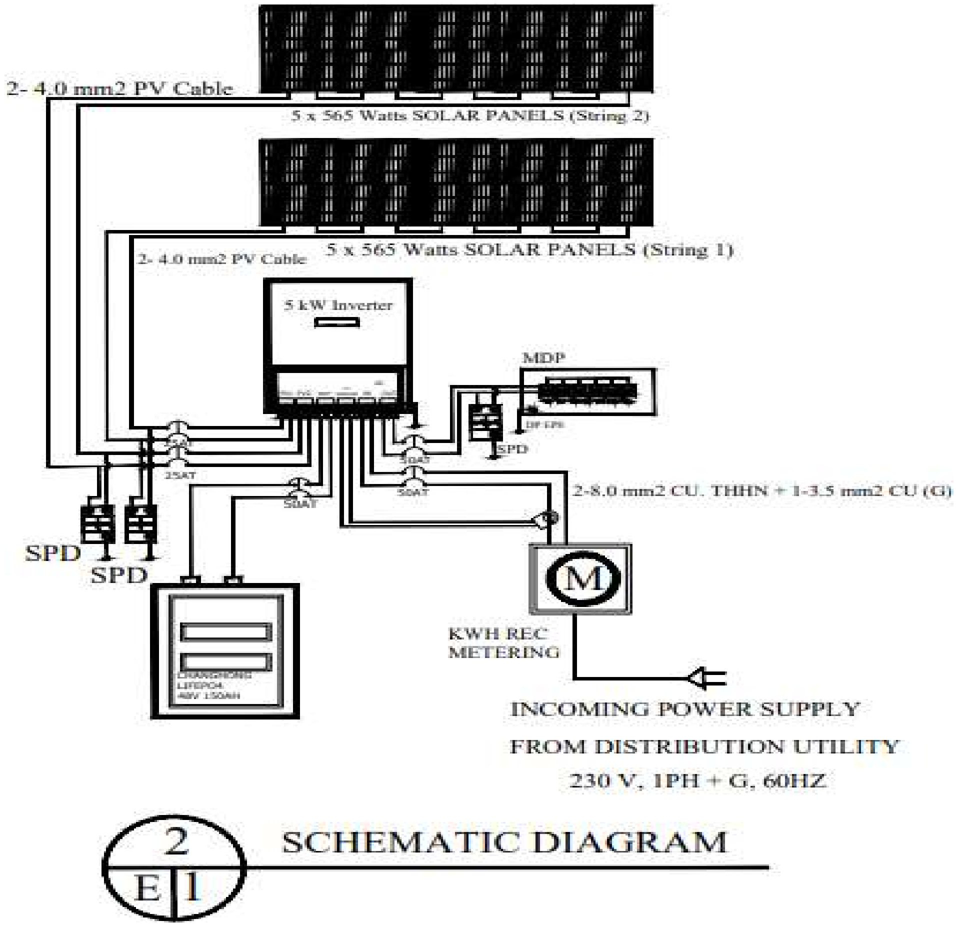

Figure 3. Schematic Diagram

Specification of the Solar Panel and Inverter

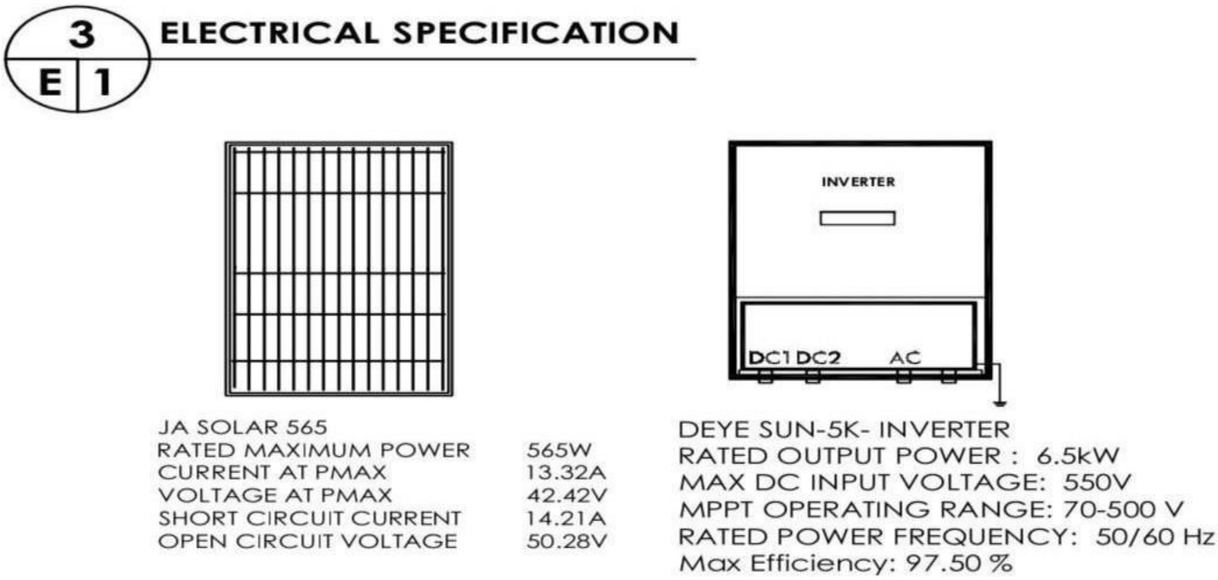

Figure 4. Solar and Battery

Block Diagram

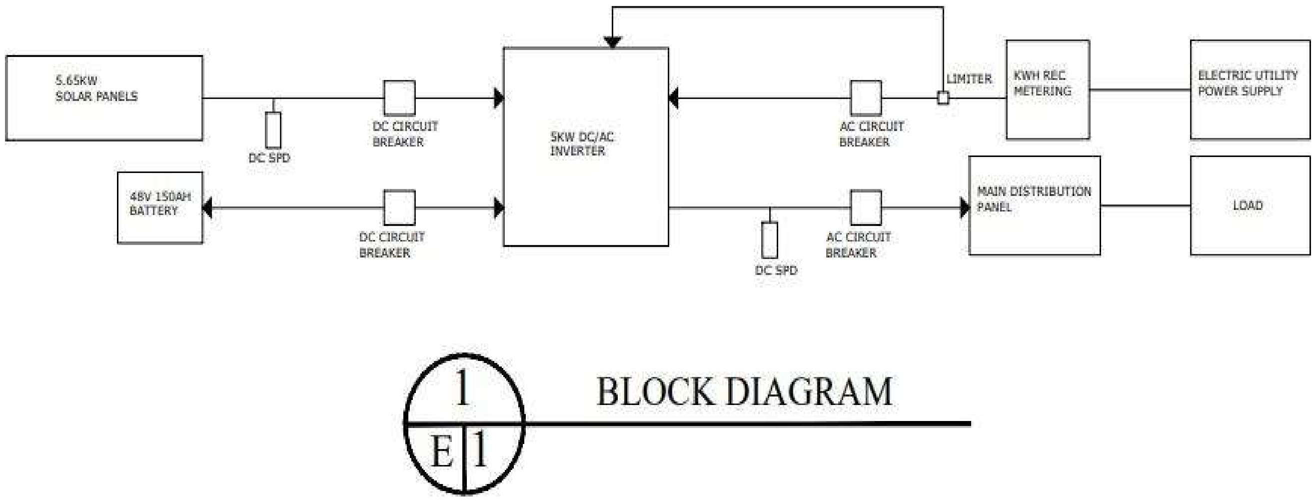

Figure 5. Block Diagram

IV. RESULT AND DISCUSSION

Battery Required

According to the residence, the connection of the battery is only for lighting. To compute the capacity of batteries, these are all the procedure: Computation for the watt-hour of the battery:

$$\text{Capacity} = \text{Volts} \times \text{Ah}$$

$$\text{Capacity} = 48\text{V} \times 150\text{Ah} \quad \text{Capacity} = 7200\ \text{Wh}$$

For the backup storage, the researcher used a typical hour (5 hours) where the battery used mostly at night time.

$$\text{Capacity } = \text{Total Load } \times \text{Backup Time Capacity } = (800 + 1500) \times 5\text{hours}$$
$$\text{Capacity } = 11{,}500 \text{ VA}$$

Calculation for the required battery:

$$\text{Battery required} = \frac{\text{Backup Time Power}}{\text{Capacity}}$$

$$\text{Battery required} = \frac{11{,}500 \text{ VA}}{7200 \text{ Wh}}$$

$$\text{Battery required} = 1.597 \text{ Batteries}$$

After the calculation of the battery. the used of one piece of 48V, 150ah lithium ion battery was still good to provide the residence electricity within a time frame of 3-5 hours' maximum. To gain a cleared understanding, this section computes the battery needed assuming the battery will provide all the load in the residence.

For the capacity:

$$\text{Capacity } = \text{Volts } \times \text{Ahs}$$
$$\text{Capacity } = 48\text{V } \times 150\text{Ah}$$
$$\text{Capacity } = 7200 \text{ Wh}$$

For the Backup Storage:

$$\text{Capacity } = \text{Total Load } \times \text{Backup Time Capacity}$$
$$\text{Capacity } = 23{,}200 \times 5\text{hours}$$
$$\text{Capacity } = 116{,}000 \text{ VA}$$

For the Required battery:

$$\text{Battery required } = \text{ Backup Time Power / Capacity}$$
$$\text{Battery required} = 116{,}000 \text{ VA / } 7200 \text{ Wh}$$
$$\text{Battery required} = 16.11 \text{ Batteries}$$

If the residence will choose to connect all the load on the battery, the residence must have larger capacity of battery to make the solar panel more efficient and productive.

Size of solar panel

The solar power system installation was undertaken by the residential property owner, according to the owner, the solar setup was intended to cover at least 70% of the residence electricity bill. It was never intended to cover the whole electricity bill. with the design and scale of the project determined primarily by the financial capacity of the owner. The average load consumption from March 2024 to July 2024 is 840.4 kWh. and the peak sun hours is 5 hours per day or 150 hours per month.

When considering the whole electricity bill:
Monthly Average Load Consumption = 840.4 kWh

Peak Sun Hours = 5 hours per day/150 Hours per month

$$\text{Total Solar Energy System (kWh)} = \frac{840.4\ \text{kWh}}{150\ \text{h}}$$

$$\text{Total Solar Energy System (kWh)} = 5.60\ kWh$$

$$\text{Considering Efficiency Loss of 75\%} = \frac{5.60\ \text{kWh}}{0.75}$$

$$\text{Considering Efficiency Loss of 75\%} = 7.5\ kW$$

Solar Panels Needed:

$$\text{Solar Panels needed} = \frac{7.5\ \text{kW}}{565\ \ \text{W}}$$

$$\text{Solar Panels needed} = 13.27\ \text{Solar Panels}$$

Although the right amount of size of solar panel is 7.5 kW, the residence can only afford at least 70% of bill reduction, which is considerate for 5.6kW. When considering covering 70% of the electricity bill: Sizing for 70% of 840.4 kwh, which is equal to 588.28kwh. Following the formula above:

$$\text{Total Solar Energy System (kWh)} = \frac{588.28\ \text{kWh}}{150\ \text{h}}$$

$$\text{Total Solar Energy System (kWh)} = 3.92\ kW$$

$$\text{Considering Efficiency Loss of 70\%} = \frac{3.92\ \text{kWh}}{0.70}$$

$$\text{Considering Efficiency Loss of 70\%} = 5.60\ kW$$

Solar Panel needed:

$$\text{Solar Panels needed} = \frac{5.60\ \text{kW}}{565\ \ \text{kW}}$$

$$\text{Solar Panels needed} = 9.9\ \text{Solar Panels}$$

Inverter Size

Monthly Average Usage: 840.4kwh

$$\text{Daily Usage} = \frac{840.4\ \text{kWh}}{30\ \text{Days}}$$

$$\text{Daily Usage} = 28.07\ \text{kWh/day}$$

By estimating the average hourly power usage and safety factor for peak loads: Average hour: 12 hours
Safety factor: 1.5

$$\text{Usage/hour} = \frac{28.01\ \text{kWh}}{12\ \text{hours}}$$

$$\text{Usage/hour} = 2.33\ k\text{W}$$

$$\text{Safety factor} = 2.33\ \text{kW} \times 1.5 = 3.5\ \text{kW}$$

The calculation concluded that the recommended sizes for the inverter having or connected with 5.65 kW solar panel was 3.5 kW to be more efficient on producing electricity within the residence. The currently installed inverter is 5 kW.

Performance of a bi-facial PV panel when connected using a limiter system.

The solar panel system connected to the limiter alone, exhibited fluctuating energy production across the four-month observation period with a total of 1070.71kWh. 417.85 kWh were harvested over a 30-day period in April 2025 with an average daily production of 13.93kWh, likely as a result of the summer season. (Table 2)

The lowest total energy production was recorded in February 2025 at 178.75 kWh, with an average daily production of 6.38kWh, indicating cooler season during that month. January 2025 and March 2025 recorded a total production of 210.65kWh and 263.46kWh, respectively, averaging a daily production of 6.8 to 8.5kWh.

The trend of increasing average production is monitored from January to April. With a slight decline in February, potentially affected by seasonal changes and reduced daylight hours.

The performance of the bifacial monocrystalline photovoltaic (PV) panel in hybrid energy setup including lithium battery, inverter, and energy management system showed measurable improvement in overall energy utilization and efficiency. In terms of kilowatt (kW) production, the system consistently generated peak outputs ranging between 5kW - 6.5kW during optimal sunlight hours. The inclusion of the battery storage allowed excess energy produced during the day to be stored and utilized during peak demand periods or at night, effectively reducing the reliance on the power grid. Moreover, the hybrid configuration helped smooth out fluctuations in energy availability, thereby enhancing the stability and reliability of the power supply within the residential application. Performance was also influenced by environmental factors such as irradiance, panel orientation, and ambient temperature.

Table 2. Data from January to April

,

Month	Number of Days	Limiter System Production (kWh)	Limiter System Average Daily Production (kWh/day)	Hybrid System Production (kWh)	Hybrid System Average Daily Production (kWh/day)
Jan-25	31	210.65	6.8	396.92	12.8
Feb-25	28	178.75	6.38	353.56	12.63
Mar-25	31	263.46	8.5	456.1	14.71
Apr-25	30	417.85	13.93	605.09	20.17
Total		1070.71		1811.67	
Average Monthly		267.68	8.9	452.92	15.08

Performance of the bifacial monocrystalline photovoltaic (PV) panel in the hybrid energy setup including battery.

The data shows 1811.67kWh were harvested from the period of January 2025 to April 2025.The average daily harvest was 15.08 kwh, equivalent to 452.92kWh of monthly harvest. While the Philippines typically receives about 5 peak sun hours (PSH) daily, where one PSH is equivalent to 1,000 watts per square meter (W/m²) of solar irradiance for one hour, this bifacial solar panel system only achieved an effective peak harvest of roughly 2.6 hours. This was due to the system design and operation. The actual amount of energy harvested during peak sun times was heavily influenced by the real-time electricity use of the household. Essentially, even when the sun was strongest, the household was not always drawing enough power to utilize the full potential of the solar panel.

Based on the data, as observed on April 29th, around 11:00 AM time when solar insolation is typically near maximum instantaneous power generation of the panel was observed to be equal to the consumption of the load. This indicates that the electrical appliances of the household were not drawing sufficient power to utilize the full potential output of the solar panels at that specific moment. Furthermore, a key factor limiting the effective peak harvest duration was the installed limiter within the system. When the instantaneous solar production exceeded the combined demand of the load and the charging capacity of the battery, the limiter acted to reduce the output from the solar panels.

Even if the solar panels had the potential to produce more energy during those high-irradiance hours, the limiter throttled their output. This effectively prevented the system from 'harvesting' its full potential during periods when local consumption (load + battery charging) was insufficient to absorb all available solar power. The energy profile of the customer in terms of monthly kWh billing, collected and estimated the average electricity consumption per month in kilowatt-hours (kWh) from the utility bills of the customer.

Customer Energy Profile (Monthly kWh Billing)

The data shows seasonal energy use patterns with higher consumption from March to June (peak summer months), presumably due to cooling demands (air conditioning and fans). After June, there is noticeable decline in usage, especially during cooler months like December to February. (Table 3). The energy consumptions were lessened and reduced by half, from 612 kWh in March 2024 to 372 kWh in March 2025, of solar energy system usage.

This kind of energy profile is ideal for evaluating the efficiency of hybrid energy setup: highlights the potential for solar savings during peak months when both sun availability and energy use are high. The energy profile also suggests how battery storage and inverters could help manage excess generation and supply during periods of low consumption

Table 3. Billing in 2024

MERALCO kWhr Billing for the Year 2024										
solar data house				0556197126			1763813841			
708BA006659				714BAG021771				Aggregate		
Date (month/yr)	kwhr	amount	peso/kWhr	meter pump	kwhr	amount	combined	kwhr	amount	peso/kWhr
Jan-24	266	3104.84	11.67	Jan-24	295	3,437.43	Jan-24	561	6542.27	11.66
Feb-24	224	2,731.35	12.19	Feb-24	344	4,294.61	Feb-24	568	7025.96	12.37
Mar-24	271	3305.6	12.20	Mar-24	341	4265.12	Mar-24	612	7570.72	12.37
Apr-24	475	5736.42	12.08	Apr-24	381	4,159.03	Apr-24	856	9895.45	11.56
May-24	601	7528.01	12.53	May-24	431	5405.42	May-24	1032	12933.43	12.53
Jun-24	641	6776.23	10.57	Jun-24	381	3819.6	Jun-24	1022	10595.83	10.37
Jul-24	353	4295.54	12.17	Jul-24	327	3980.91	Jul-24	680	8276.45	12.17
Aug-24	484	6173.06	12.75	Aug-24	243	2893.27	Aug-24	727	9066.33	12.47
Sep-24	609	7954.67	13.06	Sep-24	3	58.87	Sep-24	612	8013.54	13.09
Oct-24	586	7349.84	12.54	Oct-24	3	57.72	Oct-24	589	7407.56	12.58
Nov-24	455	5908.42	12.99	Nov-24	4	70.69	Nov-24	459	5979.11	13.03
Dec-24	425	5564.78	13.09	Dec-24	3	59.32	Dec-24	428	5624.1	13.14
Total	5390	66428.76	147.8437737		2756	32501.99		8146	98930.75	147.3416005
Average	449.17	5535.73	12.32		229.67	2708.50		678.83	8244.23	12.28
Standard Deviation	145.18	1797.01	0.70		173.41	2039.58		197.86	2099.90	0.78
Variance	21078.52	3229256.17	0.50		30071.33	4159876.80		39146.88	4409598.45	0.61

Monthly Savings in terms of Solar with Limiter and Hybrid Solar System

To assess the effect of solar energy systems on household electricity savings, the data presents comparative analysis of monthly savings across both scenarios: solar with limiter only and hybrid energy setup. The result shows that hybrid energy setup has a monthly savings of 5,752.13 pesos with standard deviation of 1,383.20. While solar with limiter, having monthly savings of 2,795.06 pesos and standard deviation of 733.52.

Economic Benefits

Solar offers great potential to save money on your monthly utility bill, and with utility bills trending upward, solar is likely to remain a good money-saving option for years to come (U.S. Department of Energy, 2023). The 8-month period breakdown of household equipped with solar with limiter only and hybrid energy setup savings was utilized to determine the load consumption reduction, return on investment and payback period.

Load Consumption Reduction

The total average load consumption from January to April 2025 is 878.67 kWh., with April 2025 having the highest load consumption of 1144.09 kWh and February 2025 having the lowest load consumption of 741.56 kWh. When connected to a limiter, the load was reduced to an average of 611 kWh, with April 2025 still the highest reduced consumption of 726 kWh following January 2025 having 590 kWh. (Table 4)

When connected to the hybrid, the load was reduced to an average of 425.75 kWh. The data shows monthly average of solar hybrid production of 452.92kWh. The month of April has the highest reduced consumption of 539 kWh and the month of March having the lowest reduced consumption of 372 kWh.

The analysis reveals that the hybrid setup reduced the total load consumption up to 48.45%, while the limiter setup reduced the total load consumption up to 69.54%. Despite the higher solar contribution in the limiter setup, the hybrid system results in a lower electricity bill, demonstrating its greater cost-effectiveness in managing energy consumption.

Table 4. Reduced Consumption

REDUCED CONSUMPTION		
DATE	LIMITER	HYBRID
January, 2025	590	404
February, 2025	563	388
March, 2025	565	372
April, 2025	726	539
Average	611	425.75

Return on Investment

To better understand the impact of installing solar energy system, the return on investment (ROI) is calculated for both solar with limiter and hybrid solar system. Gillis (2024) stated that the best way to calculate return on investment is through the formula: ROI = (Net Savings / Cost of Investment) x 100.

Equation 1.

$$ROI\ (\%) = \frac{Net\ Savings}{Cost\ of\ Investment}\ x\ 100$$

April 2025 has the highest total production of 417.85 and February 2025 has the lowest production of 178.75. The data shows monthly savings of 3,426.63 pesos. Solar with limiter has net savings of 44,119.59 pesos and the initial cost of investment is 305,000 pesos.

ROI (Solar with Limiter only):

Net Savings = ₱44,119.59

Cost of Investment = ₱305,000

$$ROI\ (\%) = \frac{₱44{,}119.59}{₱305{,}000}\ x\ 100$$

$$ROI\ (\%) \approx 14.47\%$$

Table 5. Savings (Limiter only)

Month	Monthly Production and Savings (Limiter)		
	PRODUCTION (kWh)	Peso/kWh	Peso
Jan-25	210.65	12.38	2607.85
Feb-25	178.75	12.65	2261.19
Mar-25	263.46	12.91	3401.27
Apr-25	417.85	13.01	5436.23

Average Savings (Peso)	
Monthly	Annually
3,426.63	44,119.59

In terms of Hybrid Solar setup, the average monthly savings is 5,786.72 pesos with April 2025 having the highest monthly production of 605.09 and February 2025 having the lowest production of 353.56.

The data shows that the hybrid solar setup has initial cost of investment of 305,000 pesos, 40,000 pesos for the battery and net savings of 69,440.63 pesos. (Table 6)

ROI (Hybrid Solar Setup):

Net Savings = ₱69,440.63

Total Cost of Investment = ₱345,000

$$ROI\ (\%) = \frac{₱69{,}440.63}{₱345{,}000}\ x\ 100$$

$$ROI\ (\%) \approx 20.13\%$$

Based on the calculation, the return on investment (ROI) for the system is approximately 20.13%, while the solar with limiter only has 14.47%. The two reflects a positive financial outcome over the useful life period of the system.

Table 6. Savings (Hybrid System)

Month	Monthly Production and Savings (Hybrid)		
	PRODUCTION (kWh)	Peso/kWh	Peso
Jan-25	396.92	12.38	4913.87
Feb-25	353.56	12.65	4472.53
Mar-25	456.1	12.91	5888.25
Apr-25	605.09	13.01	7872.22

Average Savings (Peso)	
Monthly	Annually
5,786.72	69,440.63

Payback Period

The payback period is th time period (generally in years) in which return is required from investment or the amount of time it takes for the positive cash flow to exceed the initial investment, without concern for the time value of money (Olatayo et al., 2018). Roseke (2024) stated that the formula of payback period is cost of investment ÷ net savings.

Equation 2.

$$Payback\ Period = \frac{Cost\ of\ Investment}{Net\ Savings}$$

Payback Period (Solar with Limiter only):

Net Savings = ₱44,119.59
Cost of Investment = ₱305,000

$$Payback\ Period = \frac{₱305,000}{₱\ 44,119.59}$$

$$Payback\ Period \approx 6.91\ years$$

Payback Period (Hybrid Solar System): Net Savings = ₱69,440.63

Total Cost of Investment = ₱345,000

$$Payback\ Period = \frac{₱345,000}{₱69,440.63}$$

$$Payback\ Period \approx 4.97\ years$$

Based on the calculations, the solar with limiter has a 6.91 years and hybrid solar system has 4.39 years before the initial investment returns. This comparison shows that the hybrid solar setup has faster payback period.

V. CONCLUSION

The use of bifacial and hybrid solar panels was the focus of study, excluding all other brands or types of panels. The findings suggest that hybrid systems, including a limiter and a battery, are overall more efficient, have greater productivity in terms of kWh and load consumption, and save on costs and energy uses, thereby significantly reducing electricity consumption and providing economic benefits in the long run for their users compared to non-hybrid systems using only a limiter. Though hybrid solar configurations may have a greater capital cost and have longer payback periods, long-term savings offer a more sustainable and economically viable alternative.

This study recommends the installation of suitably sized batteries to maximize energy storage efficiency as well as system performance. Proper adjustment of tilt angles, orientation, and mounting position of the solar modules can have a considerable effect on achieving maximum energy output. Energy systems that are efficiently managed yet use panels with high lifespan and performance offer greater savings in the long run. Furthermore, this study also recommends that installation quality, energy savings, panel performance, and matching of local environmental conditions should be closely considered when selecting and installing a hybrid solar system. In addition, extensive adoption of hybrid and bifacial solar panels highlights the need to understand their impacts on electricity consumption and system reliability.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

REFERENCES

[1] Ember. (2024, October 14). The Philippines | Ember. https://ember-energy.org/countries-and-regions/philippines-the/
[2] Al-Hussein, M., & Davidsson, H. (2023). Solar Energy system. ScienceDirect. https://www.sciencedirect.com/topics/engineering/solar-energy-system
[3] Guerrero-Lemus, R., Vega, R., Kim, T., Kimm, A., & Shephard, L. E. (2016). Bifacial solar photovoltaics – A technology review. Renewable and Sustainable Energy Reviews, 60, 1533–1549.https://doi.org/10.1016/j.rser.2016.03.041
[4] Digital, N. (2025, March 5). Bifacial Solar Modules: Efficiency & Growth in the Philippines. NATIV Techniks Inc. https://nativtechniks.com/bifacial-solar-modules-work/
[5] Maniscalco, M. P., Longo, S., Miccichè, G., Cellura, M., & Ferraro, M. (2023). A critical review of the environmental performance of bifacial photovoltaic panels. Energies, 17, 226. https://doi.org/10.3390/en17010226
[6] Hasan, A. & Dinser, I. (2020, September 15). A new performance assessment methodology of bifacial photovoltaic solar panels for offshore applications https://www.sciencedirect.com/science/article/abs/pii/S0196890420305100
[7] Department of Energy. (2023). 2020-2024 Philippine Energy Plan. Department of Energy
[8] Department of Energy. (n.d.c). National Renewable Energy Program. Department of Energy.
[9] Retrieved November 15, 2024, from https://doe.gov.ph/national-renewable-energyprogram
[10] Stancil K. (2024, November 4). The Climate Crisis Is a Cost-of-Living Crisis. The American
[11] Prospect. Retrieved November 15, 2024, from https://prospect.org/environment/2024- 11-04- climate-crisis-cost-of-living
[12] Wang, H., Oguz, E., Jeong, B., & Zhou, P. (2019). Life cycle and economic assessment of a solar panel array applied to a short route ferry. Journal of Cleaner Production, 219, 471–484. https://doi.org/10.1016/j.jclepro.2019.02.124
[13] Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2023). A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications. Results in Engineering, 20, 101621. https://doi.org/10.1016/j.rineng.2023.101621
[14] Bifacial.(n.d.).ToplaKuca.https://toplakuca.me/en/tippaneli/bifacial/#:~:text=Bifacial%20solar%20panel%20is%20a,Showing%20all%2012%20results City Labs. (2023, October 12). Lithium batteries explained. https://citylabs.net/what-are- lithium-batteries/
[15] (David, et al., 2024). Integration of solar panels in residential houses in selected barangays of San Fernando, Pampanga: Identifying challenges and proposing effective solutions.
[16] InvertersR Us. (n.d.). Hybrid Inverters. Inverters US. https://invertersrus.com/product-category/power-inverters/hybrid-inverters/
[17] Hybrid lead-acid/lithium-ion energy storage system with power-mix control for light electric vehicles. (2016, September 1). IEEE Conference Publication | IEEE Xplore. https://ieeexplore.ieee.org/abstract/document/7695531
[18] Hybrid renewable energy systems and microgrids. (2020). In Elsevier eBooks. https://doi.org/10.1016/c2019-0-03602-3
[19] Government of Alberta. (n.d.). Load limiters. Copyright © 2024 Government of Alberta. https://ucahelps.alberta.ca/loadlimiters.aspx#:~:text=A%20load%20limiter%20is%20a,and%20a%20few%20light%20bulbs.
[20] Fernández, L. (2013, August 13). Cumulative installed solar PV capacity worldwide from 2000 to 2023. Statista. https://www.statista.com/statistics/280220/global-cumulative-installed-solar- pv-capacity/
[21] Solaric. (n.d.). 5 Social impacts of solar power system in the Philippines. https://solaric.com.ph/blog/solarpowersystemphilippines/#:~:text=Solar%20power%20systems%20in%20the%20Philippines%20have%20far%2Dreaching%20social,and%20offsetting%20climate%20change%20effects
[22] Balita, C. (2024, April 10). Total solar energy capacity in the Philippines from 2012 to 2023. Statista.

[23] The Philippines energy future and low-carbon development strategies Author links open overlay panel Md Alam Hossain Mondal, Mark Rosegrant, Claudia Ringler, Angga Pradesha, RowenaValmonte-Santos https://www.sciencedirect.com/science/article/pii/S0360544218300458
[24] U.S Department of Energy. (2023, February 13). 5 Benefits of residential solar. Energy Saver. https://www.energy.gov/energysaver/articles/5-benefits-residential-solar
[25] Olatayo, K. I., Wichers, J. H., & Stoker, P. (2018, December). Renewable and Sustainable Energy Reviews.ScienceDirect.https://doi.org/10.1016/j.rser.2018.09.037https://www.statsdirect.com/help/analysis_of_variance/one_way.htm
[26] Tarek, S. (2024, June 2). A Complete Guide to Bifacial Solar Panels - Advantages and Disadvantages. AussieSolarTech.https://aussiesolartech.com.au/solarpanel/bifacialsolarpanels/#:~:text=The%20lifespan%20of%20bifacial%20solar,from%2025%20to%2030%20years.
[27] Badran, G., & Dhimish, M. (2024). Comprehensive study on the efficiency of vertical bifacial photovoltaic systems: a UK case study. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-68018-1
[28] Agopian, A. (2025, March 19). Study: Solar Battery Longevity and Reliability. Solar Insure. https://www.solarinsure.com/solar-bat