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ECONOMICALLY VIABLE CONVERSION STRATEGY OF HOUSEHOLD LIGHTING SYSTEM FROM CONVENTIONAL TO SOLAR-HYBRID

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ABSTRACT

Solar-powered and direct current energized households can be a smart choice in resorting to renewable energy. The cost of electricity continues to rise due to the rising cost of fuel used to generate electricity, depleting sources of fuel, and the adverse effect of some energy sources used to generate electricity. A survey on household's selected electrical parameters, development, and testing of a strategy of shifting and converting the lighting system of households from 220 volts alternating current (AC) to 12 volts direct current (DC), and solar was conducted. The results showed that the majority (53.85%) of the households' lighting system can be converted and the conversion strategy is technically feasible. The solar and DC lighting system also projected a savings of 326.70 pesos per month, with an estimated ROI of 27.6 % and a payback period of 3.62 years under the Philippine conditions. The shifting or conversion strategy showed excellent potential as an alternative lighting system not only for households but for other applications.

Keywords: development testing, direct current, household lighting system, shifting strategy, solar.

INTRODUCTION

Economic development has traditionally been closely associated with increased energy usage and growth Green House Gas (GHG) emissions, and renewable energy can help decouple that correlation contributing to sustainable development. Imagine if every household limits its GHG emissions by utilizing a clean alternative source of energy, it can sustain economic development without destroying the environment. Energy is a critical problem for any country's economic growth and social development [1]. In some countries, the value of power per head is greater than the age of power. Millions of people still had no access to electricity [2].

Various technologies can be applied and tested to facilitate the use of renewable energy for household use. For the electrification of remote households, hybrid renewable energy sources coupled with a diesel generator and battery have been commonly used in recent years [3-4]. The use of solar energy seems to be the right choice for households because it is readily available. The facilities needed are commercially available, and the technology can be harnessed and customized based on the need and financial capability of a household such as the standalone photovoltaic (PV) system which is the most common compared to others used mainly in rural or isolated areas and for some loads appropriate to this kind [5]. Further, shifting to direct current (DC) from alternating current (AC) is a possibility to consider since it is more likely technically compatible and more comfortable to convert to solar power if the system is DC.

The exact contribution of renewable energy to sustainable development has to be evaluated in a country-specific context renewable energy offers the opportunity to contribute to social and economic development, energy access, secure energy supply, climate change mitigation, and the reduction of negative environmental and health impacts. Emerging research presented in the existing research community is the efficient generation of renewable energy due to increased demand in society, green energy transition reforms, and economic significance [6]. Renewable energy resource research is progressing as its technical diversification guarantees energy obligation in a viable economy [7]. Further, providing access to modern energy services would support the Millennium Development Goals [8]. Moreover, eradicating energy poverty and averting dangerous climate change will require a global energy revolution in favor of the energy sources low in emissions. The United Nations has established the Sustainable Energy for All (SE4ALL) initiative to assist in this transition [9].

Today, fossil-based fuels such as oil, coal, and natural gas account for about 85 percent of all energy use in the US and around the world. Sometimes the remaining sum of a given resource is defined by the so-called reserves-to-production ratio [10]. Aside from being limited, fossil-fuel energy output results in combustion by-products or pollution. Such emissions affect our atmosphere and could exacerbate climate change. Long-term national plans consider conventional generations of power to be unsustainable sources of fossil fuel [11]. In contrast, as the name implies, renewable energy resources are replenished continuously naturally and will never be exhausted. Solar energy is a significant source of renewable energy as an alternative to reducing the use of fossil fuels and is a healthy, environmentally sustainable, unpolluted, and green source of inexhaustible energy [12]. Their use generally has a much lower environmental impact than that of conventional fuels. That is why the technologies that utilize them are often called green. Besides, renewable energy can boost the country's energy security by reducing its dependence on imports. While some green technologies are large-scale, many are also suited to private homes, especially in rural areas.

Solar-powered and direct current energized households can be a smart choice in resorting to renewable energy. Resorting to renewable energy should start in the home, in every family which is the basic unit of society. Reducing the energy used by the lighting system is

VOL. 16, NO. 22, N0VEMBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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sufficient to minimize costs and CO2 emissions [13]. This project tested a strategy for every household to have an alternative energy source for the lighting system, particularly solar and DC. One of the biggest questions is how it's getting more affordable. The strategy can be done on an installment basis. A simple technology will provide a household with an opportunity to prepare for every level of the conversion process.

This project's main objective is to develop, test, and evaluate a shifting strategy of power source systems for households. Specifically, this project sought to develop an economically viable scheme and strategy of shifting or conversion of lighting power source system for the household from conventional to solar and DC power; assess the respondents' household power consumption, electrical and lighting system; measure the illumination of commonly used light bulbs and lamps using a digital light meter; assemble a 12 volts DC back-up charger, and test the performance of each phase of lighting source conversion for the household.

RESEARCH METHOD

A. Preparation of Project Design for Solar-Hybrid Lighting System and Acquisition of Materials and Equipment

The system is a solar-hybrid type or a combination of energy sources [14]. Figure-1 is the schematic as well as the wiring diagram of the solar-hybrid lighting system. The system used two (2) double pole double throw (DPDT) selector switch which determines, through user control, the four (4) states or conditions of the system. The conditions are as follows:

a) Lighting system (LS) and battery charging (BC) "on" using the PV system. Back-up charger (BUC) "off".
b) LS and BC "on" using the back-up charger. PV system "off".
c) BC "on" using the PV system and LS "on" using the BUC.
d) LS and PV system "off". BC "on" using the BUC.

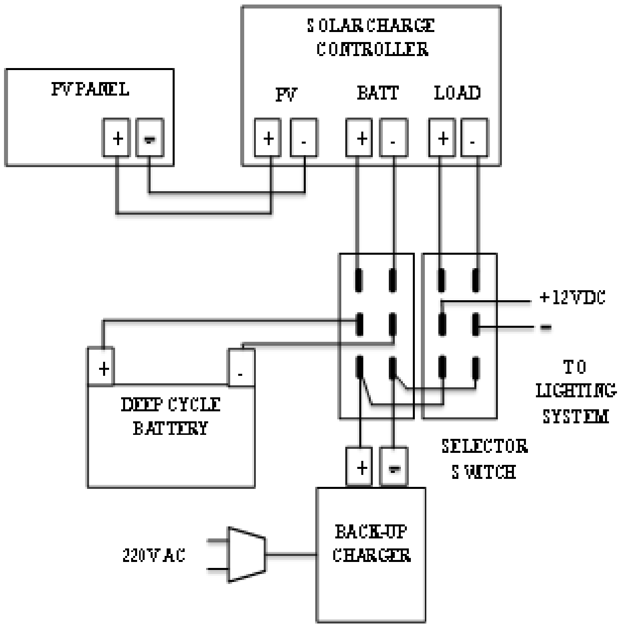

Figure-1. System schematic and wiring diagram.

Project sequence, conversion strategy, and project costing

Table-1 indicates the project sequence, shifting or conversion strategy, the cost per project phase and total cost of the system

Table-1. The project sequence, conversion strategy, and project costing.

Project Sequence	Activity/Strategy	Project Costing (Per Piece)	
		100 Watts System	50 Watts System
Phase I	Assessment of Lighting System, Assembling of Back-up Charger, installation of controllers and Replacement of Light Bulbs	4,200 (10 LED lamps)	4,200 (10 LED lamps)
Phase II	Installation, Testing, & performance evaluation of the PV Panel system	8,000	5,000
Phase III	Final and rigid testing for 6 months, revisions, and corrective measures.	Miscellaneous (2,000)	Miscellaneous (2,000)
	TOTAL COST (Note: materials only)	14,200	11,200

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B. Assessment of Households' Power Consumption, Electrical, and Lighting System as the Basis of the Conversion Process; Assembling of 12 Volts Back-Up Charger, Installation of Controllers, and Replacement of Light Bulbs from 220 Volts to 12 Volts (Completion of Phase I)

a) Sources of Electricity of Households.
b) Alternative Sources of Electricity for Households.
c) The average monthly power consumption is based on electric bills.
d) A safety device is used in the household.
e) The number of lamps/light bulbs used in the household.
f) Types of lamps/light bulbs used.
g) The wattage of light bulbs used.
h) Knowledge on 220 volts AC and 12 volts DC electrical system for households.

C. Installation, Testing, and Performance Evaluation of the PV Panel System (Completion of Phase II)

A 100 watts photovoltaic (PV) panel was installed in the selected residential unit. The 20-ampere solar charge controller together with a deep cycle battery was also installed for storage purposes. The solar charge controller will provide protection, and user control of the lighting system. The devices were temporarily but accessibly installed near the circuit breaker of the residential unit. The system was tested for a week and further revisions were made.

D. Final and Rigid Testing for 6 Months, and Corrective Measures (Completion of Phase III)

The rigid testing involved two households who volunteered to undergo the process. The owner of the households has a basic knowledge of electricity to understand the system quickly. This is very vital so that the household is protected in case of circuit breakdown and accident. The household owner also can troubleshoot and repair anytime if faults happen or are discovered.

RESULTS AND ANALYSIS

A. Assessment of Households' Power Consumption, Electrical and Lighting System; Assembling of 12 Volts Back-Up Charger, Installation of Controllers, and Replacement of Light Bulbs from 220 Volts to 12 Volts (Completion of Phase I)

For the conversion requirements of households, the household lighting system should meet the requirements of the 12 volts system. If lighting outlet (LO) wiring is not separated from a convenience outlet (CO), there is a need to rewire LO wiring or provide another wiring system for LO exclusively for 12 volts. The tables and figures below show the assessment of households' power consumption, electrical, and lighting system.

Summary of results on the assessment of households' power consumption, electrical and lighting system

Table-2. The summary of results on the assessment of households' power consumption, electrical and lighting system.

Lighting & Electrical System	Majority System Used	Percentage
a. Sources of Electricity of Households.	Local Electric Cooperative Provider Only	50%
	Local Electric Cooperative Provider and Other Sources	50%
b. Alternative Sources of Electricity for Households.	Battery	53.85%
c. Average monthly power consumption based on electric bills.	50- 100 Watts	30.77%
d. Safety device used in the household.	Circuit Breaker	53.85%
e. Number of lamps/light bulbs used in the household.	5 and below	19.23%
	16 and above	19.23%
f. Types of lamps/light bulbs used.	LED	45.66%
g. Wattage of light bulbs used.	10 watts	27.91%
h. Knowledge on 220 volts AC and 12 volts DC electrical system for households.	Familiar with 220 Volts AC System	76.92%
	Not familiar with 12 volts DC system	53.85%

The summary of electrical parameters and information needed for the conversion process is gleaned in Table-2. This served as the guide to properly select the devices needed and the strategy to be implemented. The results presented show that 50% has other sources of electricity aside from the local electric cooperative and 53.85% used battery as an alternative to electricity. The majority of the household's average monthly consumption is ranging from 50 to 100 watts with 30.77% and they are using LED lamps with 45.66%, with an average of 16 pieces bulb, mostly 10 watts. Most of the households also are using a circuit breaker as a safety device (53.85%) and

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they are also familiar with the 220 volts AC system (76.92%).

B. Installation, Testing, and Performance Evaluation of the PV Panel System (Completion of Phase II)

Current discharge testing of LED lamps

The solar charge controller regulates the DC output [15], provided protection and user control for the lighting system. For LED lamps, table 3 presents the duration of the storage battery life energizing the light bulbs. This system recommends a minimum of 50-ampere hour deep cycle battery for storage and a back-up power source. This shows that LED lights guarantee up to 40-80% energy efficiency [16]. This system is different from grid-connected PV systems which do not require batteries because they are connected to the local grid [17].

Table-3. Performance evaluation on current discharge for LED light lamps.

Wattage (Watts)	Current Discharge (Ampere)	Possible Hours of use if Energize by the System with 100Ah deep Cycle Battery
1.5	0.2	500 hrs.
3	0.3	333.33
5	0.6	166
7	0.8	125

Illumination testing of commonly used 12 volts LED lamps

As shown in Table-4, 12 volts by 5 watts LED lamps, the illumination is quite lower with 27.23 lux compared to 220 volts, 5 watts LED lamps with 31.73 lux. It is recommended that higher wattage of 12 volts of LED lamps be used to improve the illumination and conform to the standard. A boost converter that will increase input voltages to the required output voltage can be applied to improve voltage output [18].

Table-4. Illumination of commonly used 12 volts LED lamps.

Power/Wattage	Illumination (Lux) *Mean*
5 watts	27.23
3 watts	19.57
1.5 watts	11.5

Charging Performance of 100 watts Polycrystalline PV panel

The charging performance testing was done for six months from March 2018 to August 2018 using a 100 watts PV panel and 100-ampere hour (Ah) deep cycle battery. The PV panel is installed in a movable frame. Table 5 shows a summary of the PV panel system's charging performance from 7:00 am to 5:00 pm. Results revealed that current charge and charging power is higher for sunny days and clear sky [19] with an average of 4.57 amperes and 4.62 amperes compared to cloudy weather conditions with an average of 1.84 amperes and 1.45 amperes, respectively. This confirms that solar energy will become unreliable if the quality of power production is influenced by the location of the sun and seasonal weather conditions [20].

The results also reflect that the current charge and charging power is at its peak from 10:00 am to 2:00 pm, which means that charging is at its best during these hours. It also shows that the current charge and charging power is most significant from 12:00 noon to 1:00 pm. It is during this time where charging is maximized. The results also reveal that 46.17 ampere-hour is the average accumulated charging power for 10 hours during sunny days. The average accumulated charging power is only 14.5 ampere-hour when the weather is cloudy. This means that even though the weather is cloudy, charging still took place, only with lower current charges and charging power compared to sunny weather conditions. This suggests that there is a significant effect of shading in the performance of PV panels [21]. It also means that to fully charge the system, which uses a 100Ah deep cycle battery, it needs at least 20 hours of charging.

Table-5. The total and average charging performance of the photovoltaic (PV) system.

	Sunny Weather		**Cloudy Weather**	
Performance for10 hrs	PV Panel Current Charge (Ampere)	Accumulated Charging Power (Ampere hour)	PV Panel Current Charge (in Ampere)	Accumulated Charging Power (Ampere hour)
Total	45.68	46.17	18.4	14.5
Mean	4.57	4.62	1.84	1.45

VOL. 16, NO. 22, NOVEMBER 2021 ISSN 1819-6608
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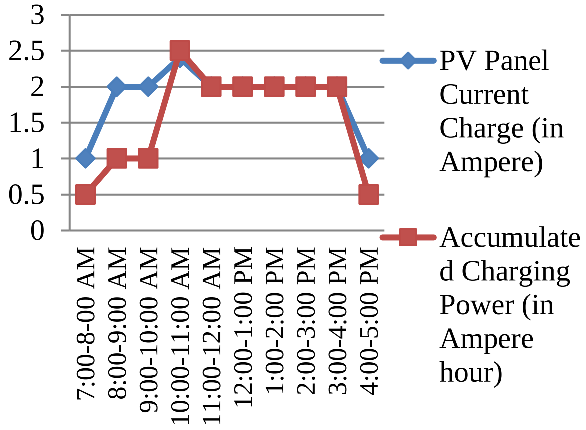

Figure-2. Summary of results of charging performance during cloudy weather.

Figure-2 details also the summary of charging performance during cloudy weather where 9:00 to 10:00 am is the peak time for charging with 2.5 current charges and charging power. Likewise, Figure-3 presents the summary of charging performance during sunny weather where 10:00 am to 2:00 pm [22] is the peak time of charging with 7.5 Ah charging power and 6 amperes charging current but charging is best from 9:00 am to 3:00 pm [23].

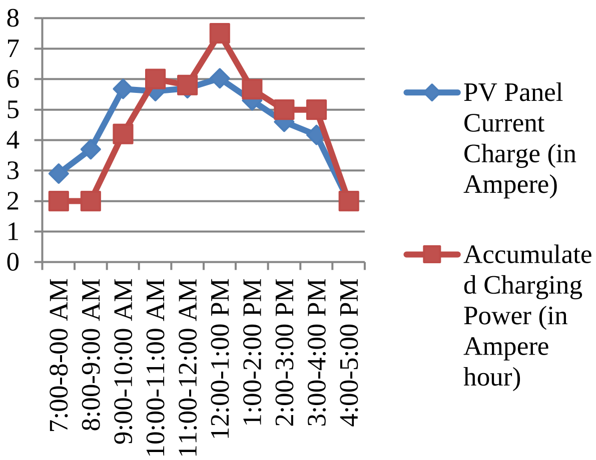

Figure-3. Summary of Results of Charging Performance During Sunny Weather.

C. Final and Rigid Testing for 6 Months, and Corrective Measures (Completion of Phase III)

The system recommends a minimum of 50 watts PV panel and 10-ampere solar charge controller. Due to its low cost, excellent efficiency, versatility, and easy installation, PV is becoming more common in power generation [24]. Higher wattage of PV panel provides greater charging capacity, and a higher current rating of a solar charge controller will provide more significant load limits. The reason for this strategy is economic viability. It will be more affordable for households to complete the system since the purchase of materials will be on a staggered basis. The initial investment will be more affordable, and every phase can be done anytime the user would like to upgrade the system. The results below show the average power consumption of two households and a power consumption computation for the lighting system.

Average power consumption for six months

Table-6 shows that the 12 volts DC lighting system household "A," has an average of 134.17 kWh monthly power consumption for six months, which is quite higher than 118.83 kWh of the 12-volts lighting system, with a difference of 15.34 kWh. The result revealed that during the months where 12 volts DC was used, there was a decrease in power consumption since it used energy-aware lighting system [25]. However, it was also found that a very minimal adjustment on power consumption was recorded in six months, which was equal to 15.34 kWh or equal to 149.10 Philippine peso or 3 US dollars. Results for household "B" registered total household power consumption with 133 kWh for 12-volts DC and 158.60 kWh for 220-volts AC with a difference of 25.6 kWh or 248.83 Philippine peso or 5 US dollars. The data was taken from the electric bills of May 2017 up to October 2017. The results represent the household's total power consumption for six months, which includes all appliances, gadgets, and other household activities with the use of electricity.

Table-6. Average power consumption for six months for two households.

Household	220 volts AC lighting system	12 volts DC lighting system
A	134.17 kWh	118.83 kWh
B	158.60 kWh	133.00 kWh

Estimated return on investment

The life of the battery varies from 3 to 5 years. Life depends on charging/discharging cycles, temperature, and other parameters [26]. The performance and life-expectancy or the system life of 25 years [27] of PV-based systems can be improved beyond the warranty period of 25 years by replacing the most degraded modules [28].

Life Span of PV Panel = 20-25 years
Life Span of Deep Cycle Battery = 3-5 years
326.70 pesos X 12 months = 3,920.4
ROI= accumulated annual savings/total project cost (100)
= 3,920/14,200 (100 watts system)
= 0.276 X 100
= 27.6 %

Estimated breakeven point

Total Project cost/accumulated annual savings 14,200/3920 = 3.62 years **(**estimated payback time)

The estimated breakeven point (3.62 years) for this system is quite impressive as compared to 13.6 years payback period for a large scale poly-crystalline PV

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system installation in Mohammedia, Morocco [29] and 5.7 years payback period for a grid-tied PV system of a University in Malaysia [30].

Sample power consumption computation for the lighting system

Table-7. Sample computation for power consumption of the lighting system.

Given (using most frequently used devices by the households):	
Most frequent wattage of lamp/lights used	10 watts
Most frequent number of lamp/lights used	16 pcs.
Average number of lighting hours	7 hours/day
Prevailing price per kWh (ISELCO I)	Php 9.72
Total wattage	10 watts X 16 pcs. = 160 watts
Total watts/day	160 watts X 7 hrs. = 1120 watt hour or 1.12 kWh/day
Lighting consumption/day	1.12 kWh X 9.72 pesos = 10.89 pesos per day
Projected savings per month using the 12 volts & solar	10.89 X 30 days = Php 326.70

CONCLUSIONS

Results revealed that current charge and charging power is higher for sunny days with an average of 4.57 amperes and 4.62 amperes compared to cloudy weather conditions with an average of 1.84 amperes and 1.45 amperes. Charging performance during cloudy weather is at the peak from 9:00 to 10:00 AM with 2.5 current charges and charging power, while charging performance during sunny weather is at its peak at 10:00 to 2:00 PM with 7.5 Ah charging power and 6 amperes charging current. The system has also a projected savings of 326.70 pesos per month, with an estimated ROI of 27.6 % and a payback period of 3.62 years. From the above findings, it can be concluded that the conversion and shifting strategy is safe and technically feasible to implement applying an economically viable scheme. The back-up charger was able to provide also enough voltage. Households consider other alternative sources of electricity and conform to the electrical system's standards and fit to undergo the conversion process. Households also preferred an LED lighting system with comparable illumination to fluorescent and other types of light bulbs. Each scheme of the shifting strategy is concluded technically feasible without significant changes in the household's electrical system and not interrupting the usual activities inside the household. The shifting or conversion strategy has excellent potential as an alternative lighting system not only for households but for other applications. However, it is also recommended that the system be presented to the local electric cooperative and proper authorities in compliance with the Philippine Electrical Code (PEC) and for further evaluation. It is also recommended that a follow-up study will be undertaken.

ACKNOWLEDGEMENT

The author acknowledges the financial support of the Campus R&D Office of Isabela State University, Angadanan Campus.

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