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Design And Installation Of 1kw Solar PV System Models

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Abstract - Solar Rooftop PV systems are becoming more popular these days as it is proven to lower electricity bills and potential contributory to lessen CO_2 emissions. Three models of 1.215 kWp solar rooftop PV systems, namely: on-grid, off-grid and hybrid were designed and installed at Room EB217 of the College of Engineering building, Tarlac State University, Romulo Boulevard San Vicente, Tarlac City in order to determine their individual characteristics in terms of (1) design analysis and wiring diagram; (2) solar PV System components and total cost of installations; (3) amount of savings incurred in the solar generation and (4) rate of return and recovery period. The result showed that for the same amount of solar panel capacity, the on-grid model has the simplest design and wiring diagram as compared to the off-grid and hybrid models. Also, the on-grid model has the least number of components and no battery and thereby it is the most economical model to install since it is 58% cheaper than the two other models. In terms of actual amount of savings incurred in the solar generation, the hybrid model offers the highest savings of P2,798.40 per month, followed by the on-grid model at P2,126.40 per month while the off-grid model had the lowest monthly savings of P1,017.60 per month. Among the three models, the on-grid offers the highest ROR on investment at 2.72% per month and the shortest period of recovery of 3 years. The hybrid had an ROR of 2.08% per month and a recovery period of 4 years while the off grid had the lowest ROR of 0.75% per month and the longest recovery period of 11 years. It is concluded that the on-grid model offers the most feasible and viable alternative in solar rooftop PV system design and installations.

Index Terms – Solar, On-grid, Off-grid, Hybrid

1. INTRODUCTION

Solar Rooftop PV systems are becoming more popular these days as it is proven to lower electricity bills and potential contributory to lessen CO_2 emissions. The importance of solar rooftop PV systems as potential to provide an alternative source of electricity is highlighted by different authors [1-3]. While in the Philippines, to achieve the vision of the Department of Energy (DOE) to triple the renewable energy (RE) capacity of the country's energy mix by 2030, the department implemented a net-metering mechanism that encourage end-users to produce on-site power using RE facilities such as solar rooftop PV system of up to 100 KW capacity. This consumer-based incentive scheme allows the excess electricity generated to be delivered to the local distribution grid and will be able to offset the consumer's power consumption.

Despite the fact of the inclusion of fiscal and non-fiscal incentives in the net-metering program of the government to accelerate the development of the country's renewable energy portfolio, actual statistics shows that as of December 2016, DOE[4] reported only a total of 681 qualified end-users having net-metering connections with total capacity of 4,185.7 KWp wherein 92.8% of these connections were serviced by the Manila Electric Company (MERALCO).

According Abdelsalam [5], solar PV systems have grown in popularity among commercial and industrial organizations in the Philippines, with three types of solar PV systems available: off-grid systems, grid-tied solar PV systems, and grid-interactive systems. Despite the growing popularity of solar panels, many homeowners are still hesitant to use them due to the high initial expenses, extended time return on investment, and concerns about the roof's ability to support the weight of solar panels.

In Tarlac City, there were other parties who signified interest in installing solar rooftop PV systems but were hindered to do so due to its high initial cost and the technicalities in the preparation of electrical plans and other documents to become legally recognized by both the Energy Regulatory Commission and the local electric utility as a qualified end-user of renewable energy facility.

Tarlac State University (TSU) in its category as a technological university in region three, aims to address the needs and issues of its stakeholders related to any technological trends in its area of influence. The researchers in the College of Engineering thought of proposing this project that would help various clientele in their search for "technical guidelines" as they consider installing solar PV system, by providing them actual laboratory models of solar rooftop PV systems to include technical specifications written in a form of brochure but data provided in the brochure must be backed up with localized research and development studies, hence, this study is proposed. Moreover, the present project found its inspiration from the research study of Yildiz, F. and Coogler, K.,[6] where the future direction of the present study will be patterned to their goals. Furthermore, similar problem mentioned in [7], and that of the findings of Ahmed [8] that there were three public-policy barriers to rooftop-solar expansion in the Philippines: Regulatory, administrative, and financial, may also be considered as future developments for the present study.

This paper is focused on designing and installing three separate 1 kW Solar PV Systems, namely: (1) Grid-Tied, (2) Hybrid and (3) Off-Grid.

According to [9] a grid-tied solar system – also referred to as on-grid – uses solar panels and other components to turn sunlight into electricity for your use, while your home remains hooked up to the local utility. An array of solar panels is installed (usually on the roof of the building) and connected to the home's electrical system. The electricity is used first to power the home's immediate electrical needs. When those needs are met, the additional electricity is sent out to the grid through your utility meter. In this instance, your utility grid functions as a part of the overall solar system, which is referred to as grid-tied solar. A successful installation of this type of solar system was done by Yan [10].

Hybrid solar systems generate power in the same way as a common grid-tie solar system but use special hybrid inverters and batteries to store energy for later use. This ability to store energy enables most hybrid systems to also operate as a backup power supply during a blackout, like Uninterruptible Power System (UPS) [11]. The study of Vedpathak, et. al., [12] is an example of this system.

An off-grid solar system is a solar panel system that generates electricity, stores that power in solar batteries, and runs independently from the power grid [13]. This type of system is useful only when there is requirement of load to run in night-time or in other time when sunlight is unavailable for some period [14] and an example of design and cost analysis for this type of system was done by Ahsan, et. al. [15] and that of Javed, et.al. [16].

The general objective of the project is to design and install at the College of Engineering building, three laboratory scale 1 kW Solar PV System Models as actual demonstration project in generating data for technical guidelines brochures. Specifically, for each of the models, the project aims to: (1) conduct design analysis; (2) determine the solar PV System components and total cost of installation; (3) determine the amount of savings incurred in the solar generation and (4) compute the rate of return and recovery period.

2. RESEARCH METHOD

The project used Research and Development Method which is focused on electrical design and installation, observation and comparison of the three solar PV models. The following steps summarized the procedure of the project:

1. Conduct design analysis for three 1 kW solar PV system models. In this step, electrical circuit diagrams with design computations were prepared and drawn to serve as wiring guide for installers. In the design computation, proper size of wires and overcurrent circuit protections both for the DC and AC side were determined and specified. Also, the proper ratings of inverters and solar charge controller, battery connections and other components were identified and specified.
2. Prepare bill of materials and cost estimates based on the design analysis.
3. Purchase the materials through government procurement process (RA 9184). Tarlac State University through its procurement unit was in-charged of the purchasing of all the items following RA 9184.
4. Assemble and install the materials for each model. Once the items were completed, the installations commenced upon approval of proper authorities.

5. Perform testing and commissioning. Testing and commissioning were done to ascertain the functionality of the assembled models.
6. Perform periodic observation. Periodic refers to daily on the first week of operation and monthly thereafter.
7. Adjustments to correct errors (if any).
8. Report Writing.

3. RESULTS AND DISCUSSION

The following represent the results and discussion relative to the statement of objectives posted in section 1.

3.1. Design Analysis for 1 kW On-Grid, Off-Grid and Hybrid Solar PV Systems

The design analysis follows the steps given by [14] but with some modifications suited for the present study. Figure 1 shows the design analysis and wiring diagram and actual set-up for 1 kW Solar PV Systems for (a) On-Grid, (b) Off-Grid and (c) Hybrid.

Design Analysis and Wiring Diagram for On-grid Model	Actual Set-up

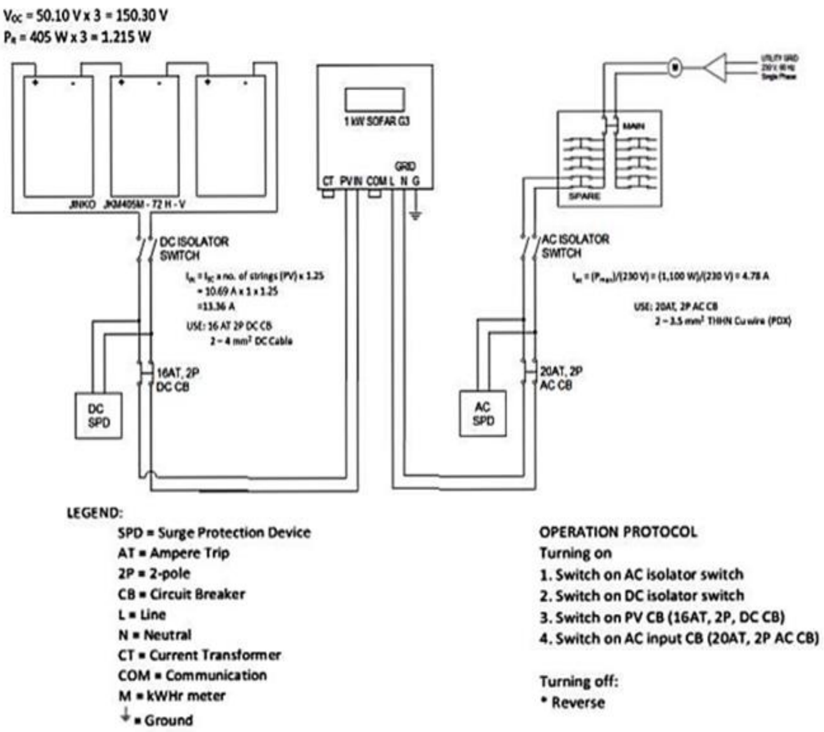


Figure 1 (a) On-Grid Model

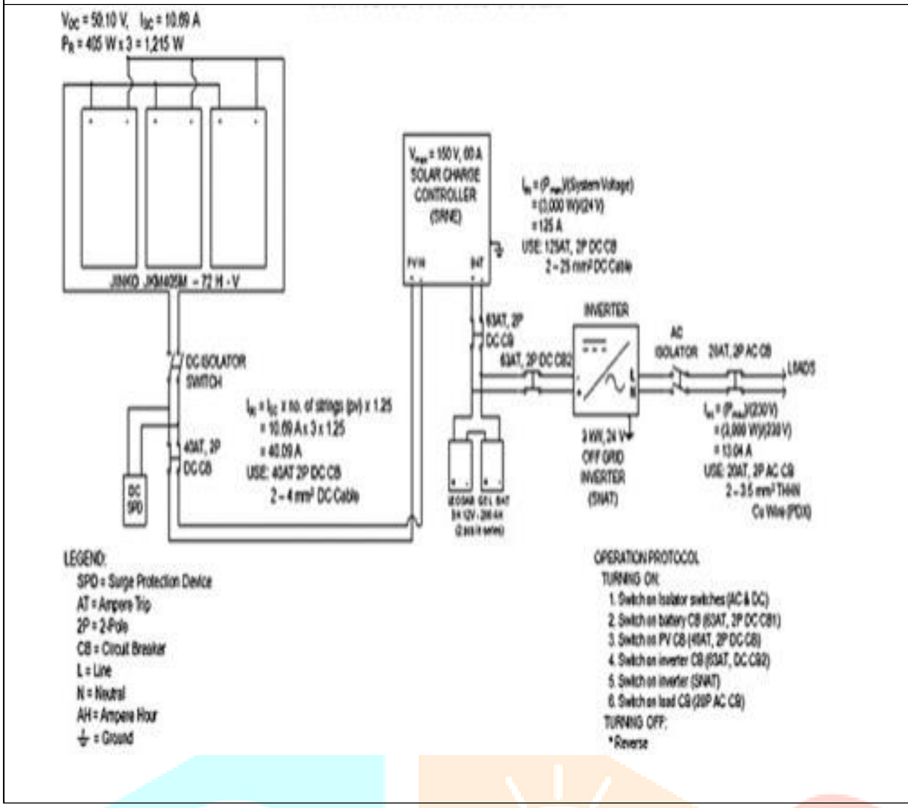
Design Analysis and Wiring Diagram for Off-grid Model	Actual Set-up
	

Figure 1 (b) Off-Grid Model

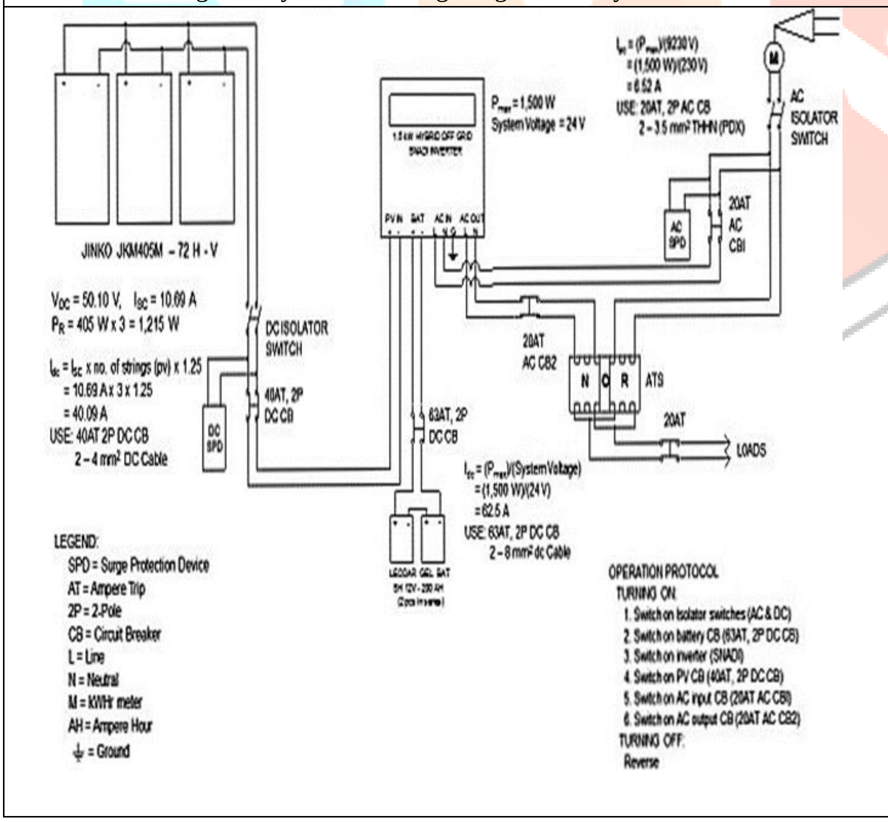
Design Analysis and Wiring Diagram for Hybrid Model	Actual Set-up
	

Figure 1 (c) Hybrid Model

Step 1: Site inspection and radiation analysis

Room EB7 of Tarlac State University, Tarlac City, is in Central Luzon, Philippines at latitude and longitude of 15.48°N and 120.58°E, respectively. This geographical location of Tarlac City implies that the solar array should be inclined at an optimal angle of about 12.57° facing southward for all year round to maximize solar energy receive if it is oriented fixed [17]. The average radiation of this location is about 5.52 kWh/m^2/day [18]. In PV system design, the lowest daily average irradiance is usually selected as basis for sizing the PV panels, which is 4.134 kWh/m^2 during August shown in Table 1, is used in this study. The monthly average radiation profile is shown in Figure 2.

Table 1. Monthly average radiation data of the site

Month	Daily Average Irradiance (kWh/m^2/day)
January	5.589
February	6.322
March	6.744
April	6.849
May	5.893
June	5.565
July	5.054
August	4.134
September	5.087
October	5.095
November	5.144
December	4.741

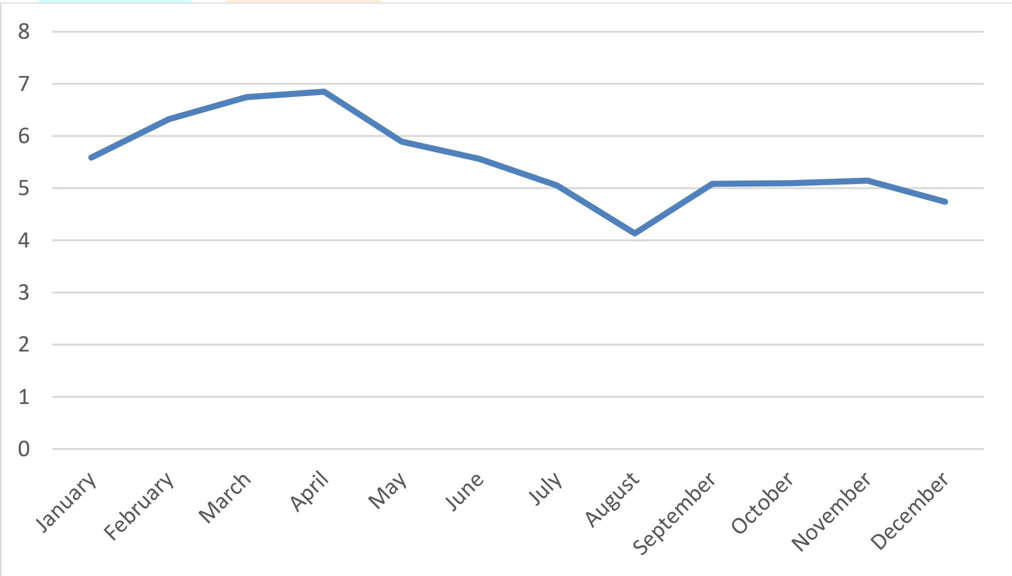


Figure 2. Monthly average radiation profile of the site

Step 2: Calculation of building load requirement

A 1kW solar PV system can supply a typical small household that had the following consumption as shown in Table 2.

Table 2. Total energy consumption for a small household

LOAD	QTY	POWER (Watt)	TOTAL POWER (Watt)	DAILY USAGE (Hours)	ENERGY CONSUMPTION (Watt-hours)
LED Lights (resistive)	3	7	21	11	231
Electric Fan (inductive)	1	60	60	12	720
Refrigerator (Inductive)	1	200	200	14	2,800
Total			281		3,751

The load consumption in a household is vital in solar PV system design, specifically for off-grid and hybrid systems where batteries are part of the component. The size of the battery and rating of the inverter will depend on the load consumption. However, for an on-grid system where no batteries connected, the rating of the inverter is dependent on the total power rating of PV panels connected.

Step 3: Choice of system voltage and components

After calculating load requirement, the next step is to decide on what DC voltage will be selected [19]. In this design, 24Vdc for the battery and a maximum of 150Vdc for the solar charge controller is chosen.

Step 4: Determine capacity of Inverter

The required rating of the inverter for the on-grid model depends on the maximum PV power. The maximum PV power is predetermined to be 1,215 Watts (3 pieces of 405W Jinko JKM405M-72H-V). Therefore, the rating of the inverter is at least 1,215 Watts. The nearest available standard rating is 1,500W. As an example, SOFAR 1100TL-G3 grid-tied inverter with a maximum DC power capacity of 1,500 Watts is selected.

On the other hand, inverter capacity for both off-grid and hybrid models can be determined based on load requirements of the building following [19]. Using data in Table 2, inverter capacity is determined as:

Inverter capacity = [281+3.5(60+200)] x 1.25 = 1,488.75 Watts (so a 1,500 Watts is to be chosen)

Step 5: Determine capacity of Battery (applicable only to off-grid and hybrid models)

Battery capacity is determined using the formula [20]:

$$C_x = \frac{N_c x E_L}{DOD_{max} x\, V_{system}\, x\, \eta_{out}}$$

Where,

C_x = Required battery capacity
N_c = Number of days of autonomy = 1 (adopted in this study)
E_L = Estimated load energy in Wh = 3,751 Wh (from Table 2)
DOD_{max} = Maximum depth of discharge = 0.50 for Lead Acid type
V_{system} = 24Vdc (from Step 3)
η_{out} = Battery loss or efficiency = 0.85 for Lead Acid type [21]

$$C_x = \frac{1\ x\ 3{,}751}{0.50\ x\ 24\ x\ 0.85} = 367.75\ Ah \text{ (400 Ah is chosen)}$$

Step 6: Solar PV array specification and design layout

The proposal to install 1 kW output for each model was originally based on the assumption that solar panels were 2 pcs of 500W for each model, but the actual solar panels procured was three pieces of 405W each. As a result, the actual models would have a power output capacity of 1.215kWp each. To achieve higher power rating, PV panels may be connected in series or in parallel [15].

Sizing of PV module requires the use of the formulas:

$$PV\ Power = \frac{Total\ Daily\ Consumption}{Sun\ Peak\ Hours} x\ 1.3$$

$$No.of\ PV\ Modules = \frac{PV\ Power}{Rating\ of\ PV}$$

Where:
Rating of PV is the power rating of each module.
Sun Peak Hours is based on the lowest daily average irradiance of the location which is 4.134 hours and 1.3 is a factor accounted for losses.

Applying these formulas, the required size of PV is

$$PV\ Power = \frac{Total\ Daily\ Consumption}{Sun\ Peak\ Hours} x\ 1.3 = \frac{3{,}751\ Wh}{4.134\ h} x\ 1.3 = 1{,}179.56\ W$$

$No.of\ PV\ modules\ = \frac{1{,}179.56W}{405\ W} = 2.912$ (use 3 pcs. of 405W each with a total power of 1,215W)

The actual PV module chosen for this study was Jinko solar module type: JKM405M-72H-V having the following parameters and value as shown in Table 3.

Table 3. Solar module specifications

Parameters	Value
Maximum Power (Pmax)	405 W
Power Measurement Tolerance	±3%
Maximum Power Voltage (Vmp)	42 V
Maximum Power Current (Imp)	9.65 A
Open Circuit Voltage (Voc)	50.1 ± 3%
Short Circuit Current (Isc)	10.69 A ± 4%
Maximum System Voltage	1500VDC
Maximum Series Fuse Rating	20 A
Operating Temperature	-40°C to +85°C
Application Class	A
Fire Class	C
Weight	22.5 kg
Dimension	2008x1002x40 (mm)
STC	1000W/m^2, AM1.5, 25°C

For on-grid model, the design layout is series connection of these three modules with a total voltage and current of:

V_{PV}= 3 x 42V = 126 V and I_{PV} = 9.65A

For off-grid and hybrid models, the design layout is parallel connection with a total voltage and current of:

V_{PV}= 1 x 42V = 42V and I_{PV} = 3x 9.65A= 28.95A
Step 7: Charge controller specification (applicable to off-grid model)

Sizing of solar charge controller (SCC) needs the specifications of PV panel: V_{oc} = 50.1V and I_{sc} = 10.69A and the maximum voltage (Vmax) that the SCC can manage is 150V.

No. of series PV panel = V_{max}/V_{oc}=150V/50.1V=2.99≈2 (only 2 will be managed if series connection). To accommodate all three PV panels, they should be connected in parallel. Then the charging current, I_{cc}, will be:

$I_{cc} = I_{sc}$ x No. of PV panels x 1.25=10.69x3x1.25=40.09A. So, select the nearest available size of 50A or 60A.

Step 8: DC Cable Sizing.

DC cable sizing exists in two types: Inverter to battery and Solar PV to inverter. For on-grid models, only the solar PV to inverter DC cable is applicable while for off-grid and hybrid models, both are to be specified.

Inverter to Battery DC Cable Sizing

Inverter to battery cable sizing is determined using the formula [14],

$$I_{B1} = \frac{TP}{\eta * V_{LB}}$$

Where,

I_{B1} is the current from the battery to inverter,
TP is the sum of load wattage,
η is efficiency of inverter and
V_{LB} is the allowable set lowest voltage of the battery.

If TP is based on actual total power (equal to 281 W from Table 2), η = 85% and V_{LB} = 22.2V, the current I_{B1} and the size of DC cable are:

$I_{B1} = \frac{TP}{\eta * V_{LB}} = \frac{281}{0.85 * 22.2} = 14.89A * 1.25 = 18.61A$ (use 13 AWG, 2.123mm^2, 1.64 mm diameter)

Or if TP is based on the actual capacity of inverter (equal to 1,500W obtained from step 4), I_{B1} and the size of DC cable are:

$I_{B1} = \frac{TP}{\eta * V_{LB}} = \frac{1500}{0.85 * 22.2} = 79.49 * 1.25 = 99.36A$ (use 3 AWG, 26.7mm^2, 5.83 mm diameter)

Solar PV to Inverter DC Cable Sizing

Solar PV to inverter DC cable sizing is determined using the specifications and type of connections of PV panels together with the application of formula [22].

$$I_{DC} = I_{PV} * 1.25 * 1.25$$

Where,

I_{DC} is the current from solar PV to Inverter
I_{PV} = 9.65 A for on-grid model (obtained from step 6)
I_{PV} = 28.95 A for off-grid and hybrid models (obtained from step 6)

The current from solar PV to inverter and the required DC cable sizes are:

For on-grid model: $I_{DC} = 9.65A * 1.25 * 1.25 = 15.08A$ (use 4mm^2 TWIN PV Cable Aluminum)
For off-grid and hybrid models: $I_{DC} = 28.95 * 1.25 * 1.25 = 45.23A$ (use 4mm^2 TWIN PV Cable Aluminum)

The 4 mm^2 TWIN PV Cable Aluminum has an ampacity rating of 50A.

Step 9: PV Module orientation

As mentioned in step 1, solar array for Tarlac City should be tilted at 12.57° facing south [19].

Step 10: Cost Analysis

Cost analysis using the Net Present Value (NPV) method follows the following steps outlined in [14]. Data used in the analysis given in Table 4 and the summary of the comparison among the three models are given in Table 5.

Table 4. Data used in cost analysis

Parameters	Value
Average number of daily sunshine hour	5.52 hour
Solar PV system efficiency	70%
Module efficiency, on first year	97.5%
Module efficiency, on the 25th year	83.13%
Rate of electricity	Php16 per kWh
Expected increase rate of electricity	3% per year
Inflation rate	6.10%
Discount rate	6.25%
Interest rate in the bank	8.75 % per annum
Maintenance rate	10% per annum
Projected lifespan of the system	25 years

Table 5. Cost analysis summary among the three models

1 kW Model	Initial Investment (Php)	Net Savings after 25 years (Php)	Net Present Value of Savings (Php)	Payback Period (years)	Bank fixed deposit to pay bill, sustained
On-grid	78,092.00	710,685.04	686,224.50	4	Until 3rd year
Off-grid	198,023.07	693,008.83	669,156.67	8	Until 10th year
Hybrid	197,463.07	693,568.83	669,697.40	8	Until 10th year

Initial investment includes the cost of materials and installation plus the present cost of future investment in batteries. Table 5 shows that the on-grid model had the lowest initial investment and shortest payback period. If money from initial investment were to be bank deposited at a rate of 8.75% per annum and will be used to pay the monthly electricity bills, it would last for 3 years for on-grid model while 10 years for both off-grid and hybrid models.

3.2. Solar PV System Components and their Total Cost of Installations

Table 6 shows the needed components and total cost of installations for each of the three Solar PV models.

It can be observed from Table 6 that for a 1.215 kWp solar model set-up materials and cost of installations for an on-grid system is the cheapest among the three models amounting to P78,092.00 or 58% cheaper than the off-grid and hybrid models. This was due to the characteristic of on-grid models having no batteries, thereby no additional cost incurred for batteries. This is consistent with the project of Yan [10], the grid-tied system she developed was cost-effective since it costs nearly half of the estimated budget. On the other hand, both off-grid and hybrid models shared the same total cost of installations amounting to P135,044.00 and P134,484.00, respectively.

Table 6. Solar PV System Components and their Total Cost of Installations

No.	Components	Cost Incurred for 1.215kWp		
		On-Grid	Off-Grid	Hybrid
1	405W Solar Panels (JINKO) @ P9500 each	P 28,500	P 28,500	P 28,500
2	2.1 m Aluminum Railing @ P750 each	3,000	3,000	3,000
3	L-Roof Brace with rubber @ P150 each	1,800	1,800	1,800
4	Mid Clamp Aluminum @ P75 each	300	300	300
5	End Clamp Aluminum @ P75 each	300	300	300
6	4mm^2 Twin PV DC Cable @ P175 per m	3,500	3,500	3,500
7	8-way Panel Box HT series @ P600 each	600	600	600
8	HDPE Flexible Conduit 1”Ø @ P90 per m	1,800	1,800	1,800
9	DC Isolator Switch @ P1500 each	1,500	1,500	1,500
10	AC Isolator Switch @ P1500 each	1,500	1,500	1,500
11	LCD Multimeter Power Meter @ P2400 each	2,400	2,400	2,400
12	2m Cable Tray 40x40mm @ P500 each	1,000	1,000	1,000
13	20AT AC Miniature CB @ P400 each	400	400	400
14	DC Surge Protection Device @ P1050 each	1,050	1,050	1,050
15	AC Surge Protection Device @ P600 each	600	600	600
16	12 AWG PDX Wire THHN @ P40 per m	200	200	200
17	Grounding Rod with Clamp @ P1000 per set	1,000	1,000	1,000
18	12AWG Grounding Wire (Green) @ P60 per m	1,200	1,200	1,200
19	1inch dia. Steel C Clamp @ P20 each	200	200	200
20	Cable Tie Plastic 20cm by 2cm @ P3 each	75	75	75
21	No. 6 Tox with Screw @P2 each	50	50	50
22	MC4 Connector @ P100 per pair	100	400	400
23	16AT DC Miniature CB @ P500	500	0	0
24	12 AWG Royal Cable 3C @ P150 per m	150	0	0
25	1kW Grid-Tie Inverter (SOFAR G3) @P18000	18,000	0	0
26	40AT DC Miniature CB @P650 each	0	650	650
27	200AH 12V Gel Solar Battery @P 16000 each	0	32,000	32,000
28	Battery Cable 25mm^2 30cm @ P300	0	300	300
29	Battery Cable 25mm^2 120cm @ P1500 per pair	0	1,500	1,500
30	63AT DC Miniature CB @ P650	0	650	650
31	W MC4 Connector @ P600 per pair	0	600	600
32	24V 3kW Off-Grid Inverter (SNAT) @ P20000	0	20,000	0
33	24V 60A MPPT SCC (SRNE) @ P13500	0	13,500	0
34	24V 1.5kW Off-Grid Inverter (SNADI) @ P33000	0	0	33,000
35	TOTAL COST OF MATERIALS	69,725.00	120,575.00	120,075.00
36	12% LABOR COST OF INSTALLATIONS	8,367.00	14,469.00	14,409.00
37	TOTAL COST OF INSTALLATIONS	**78,092.00**	**135,044.00**	**134,484.00**

The inflated cost of installations associated with solar PV models with batteries, such as off-grid and hybrid, often caused discouragement for a prospective customer/end-user to purchase and install these models. In addition, batteries are expected to have a replacement cost every up to 6 years according to [23]. Also, for off-grid and hybrid models the higher cost of maintenance such as cleaning of solar panels, inverter, solar charge controller and battery poles, checking of every component, etc. are to be expected. The off-grid and hybrid models, though, have an advantage over the on-grid model in terms of maintaining a continuous supply of electricity, but over-all in terms of cost the on-grid model is still the most economically viable set-up among the three. Moreover, the on-grid model can be applied for net-metering mechanism wherein part of generation can be diverted back to the electricity provider to be credited to the owner's monthly electric bill, which translates to additional amount of savings to the owner.

3.3 Amount of Savings in the Solar Generations

To determine the actual amount of savings in the solar generations, each of the three models were connected to constant load and operated for a period of seven days, monitored, and recorded their corresponding solar energy generations. The result is shown in Table 7 and the comparison is shown in Figure 3. The daily average for the on-grid model is 4.43 kWh, that of the off-grid is 2.12 kWh and for the hybrid is 5.83 kWh. It is noticeable that the off-grid model had the lowest actual daily average generation of 2.12 kWh. This is due to the low battery state of charge often encountered by the system that enables the load to be disconnected. This disconnection is done to protect the battery from over-discharging beyond its allowable depth of discharge. During load disconnection, there were no readings on the kWh meter thereby resulting in a lower actual daily generation. Also, during load disconnections, the solar panel continuously generates electricity to solely charge and replenish the loss charge of the battery.

Table 7. Actual daily kilowatt-hour solar energy generations

Model	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Daily average
on-grid	2.61	3.40	5.00	4.00	5.00	6.00	5.00	4.43
off-grid	1.02	4.52	3.87	2.00	1.40	1.00	1.00	2.12
hybrid	2.51	6.22	8.00	9.00	1.08	9.00	5.00	5.83

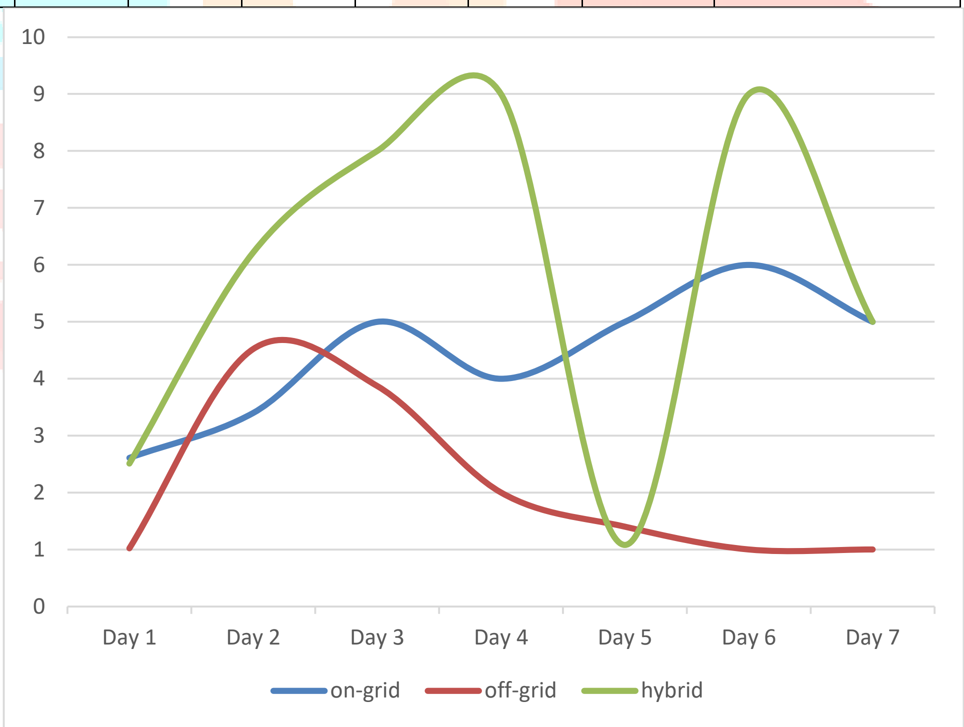


Figure 3. Solar energy generations among three models

The actual monthly savings is computed based on the following formula:

Monthly savings = Daily Average Generation x 30 days x TEI rate per kilowatthour,
where daily average generation is taken from actual measurements recorded by energy meters for each model while TEI rate is fixed at P16 per kWh. The actual amount of monthly savings for each model is shown in Table 8 and the comparison is shown in Figure 4.

Table 8. Amount of Savings in Solar Generations

Model	Actual Daily Average Generation	Actual Monthly Savings
On-grid	4.43 kWh	P2,126.40
Off-grid	2.12 kWh	P 1,017.60
Hybrid	5.83 kWh	P2,798.40

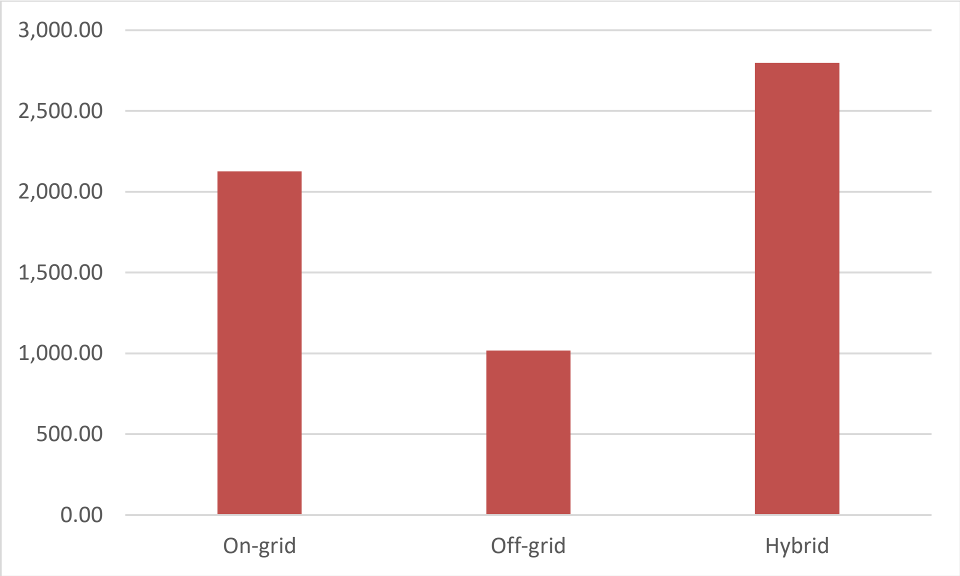


Figure 4. Monthly savings in solar generations

In terms of actual monthly savings, the hybrid model offers the highest amount of P2,798.40, followed by the on-grid amounting to P2,126.40 while the off-grid model had the lowest actual monthly savings of P1,017.60.

3.4 Rate of Return and Recovery Period

Table 9 shows the comparison for the three solar PV models in terms Rate of Return (ROR) and Recovery Period (RP). The ROR is computed based on the formula:

$$ROR = \frac{Actual\ Monthly\ Savings}{Investment\ Cost}$$

While the RP is computed based on the formula:

$$RP = \frac{Investment\ Cost}{Actual\ Monthly\ Savings}$$

Table 9. Rate of Return and Recovery Period

Model	Investment Cost	Actual Monthly Savings	Rate of Return (ROR)	Recovery Period (RP)
On-grid	P 78,092.00	P 2,126.40	2.72 %	36.72 months or 3 years
Off-grid	P 135,044.00	P 1,017.60	0.75 %	132.71 months or 11 years
Hybrid	P 134,484.00	P 2,798.40	2.08%	48.06 months or 4 years

Of the three models in comparison, the on-grid model has the most promising rate of return of 2.72% with a recovery period of 36.72 months or 3 years. The hybrid model is the second in rank with an ROR of 2.08% with a recovery period of 48.06 months or 4 years. The off-grid model on the third rank with an ROR of 0.75 % and a recovery period of 132.71 months or 11 years. Because of these comparisons, the on-grid model is the most popular choice by investors since it has a lower investment cost and have a fast recovery period not to mention the additional savings to be incurred when the on-grid system is abled for net-metering. However, in certain locations where access to utility grid is not possible, the off-grid model is preferred to power household lightings and appliances.

4. CONCLUSION

Three models of solar PV systems of the same input capacity of 1,215 Watts each were compared and presented in this paper. The three models differ with each other in terms of wiring design, system components, initial costs, actual monthly savings, rate of return and period of recovery. With these parameters, it is concluded that the on-grid model offers the most feasible and viable alternative in solar rooftop PV system design and installations.

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