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Case Study: A Simulation Design of An Off-Grid Solar PV System for Swiftlet Farming in Bintangor Sarawak Using PVsyst Software

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Abstract: Swiftlet bird’s nest is valued for its nutritional and medicinal qualities, highly prized by Asian communities globally. With rising consumers demand and a growing middle class, this industry is lucrative yet connectivity to the swiftlet farms remains an issue due to its rural location (close to bird’s natural habitats) and far from grid connection or any electricity supply. Thus, the demand of a completely off-grid powered solar PV system is highly sorted and viable. In this case study, PVsyst simulation software was utilized to design a fully off-grid photovoltaic (PV) solar system for a swiftlet farm in Bintangor, Sarawak, at GPS coordinates 2°10'05.7" N, 111°38'29.8" E. Currently powered by a grid-based supply, this study aims to transition the site to a sustainable off-grid solar PV system, serving as a model for future swiftlet farm developments in Sarawak. The site covers a total area of 847.32 m² (an irregular heptagon with a maximum length of 58 m and width of 17 m). At the design and estimation stage, it was determined that 252 solar panel modules, 240 batteries, 21 charge controllers, and a 11,000 W (DC to AC) inverter would be required to meet these needs yielding a total of energy of 74.49 MWh/year.

Keywords: PVsyst, Off-grid swiftlet farm, Design, Case Study.

I. INTRODUCTION

Malaysia is amongst one of the major producers for swiftlet bird’s nest apart from other south-east Asian nations such as Indonesia, Thailand, Vietnam and The Philippines. The swiftlet bird’s nest also known as “Caviar of the East” is highly appreciated for its nutritional and traditional medicinal values by the Asians communities worldwide. With the paradigm shift in the consumers’ spending and ever-growing middle class coupled with the crave for bird’s nest, this industry is very lucrative and rewarding one with reported total exports of this industry in 2020 being 5,654 metric tonnes, worth RM1.2 billion according to Malaysia’s Ministry of Agriculture and Food Industries (MAFI) [1]. To be able to tap a handsome or sizeable profit from this farming, one needs to balance between expenditure and outputs as well as minimize wastage in its operation [2, 3]. Technically, prior to erecting a new bird house, the employers and the investors normally have to identify a good and sustainable location of the bird house whether there are any large and sustainable flock of birds habiting or nesting surrounding area of the intended location/farm [4]. In other words, the swiftlet farm needs to avoid any factories or industry areas which is laced/contaminated with heavy toxic materials, smoke or even noise. Therefore, a swiftlet farm ideally would be built in the rural area or closer to its natural habitats in order to have a good environment and outputs such as low noises, disturbances, and plenty of food availability [4]. Within the circle of this business trade practices, it is widely practised that operator will just purchase and install the off-grid solar power system for a swiftlet farm based on rough estimations and experiences or following any “workable” words-of-mouth success trial-error practices from other operators. In this aspect, operators are not considering or taking into account the critical issues and optimization in their system. Thus, the consequences are poorly and inadequate output estimation and high wastage. Another compounding factor due to its preferred rural and isolated location of an ideal swiftlet farm, high connection cost to existing power supply is unavoidable especially with the lack of transportation modes, challenges and difficulties in electrical such as cable laying, structure building, land dispute due to power cables laying might be crossing over various and multiple lands in connecting to a power grid. Not only then that, there also have a high operating cost incurred in a long run such as electrical bill, water bill, salary, and maintenance fee over the time. Subsequently, the cost of the swiftlet farm will be increased indirectly. Due to these constraints, an off grid solar PV system is preferred to reduce the cost of swiftlet farm in the long run. In this study, the simulation software named PVsyst to be used to estimate the outputs and efficiencies based on weather data, shading, losses and etc, precisely based on the GPS location of the swiftlet farm. Further optimization to be carried out to increase the outputs and minimize loses using PVsyst simulation software.

Our Contributions: Main contribution of this paper is on a systematic design of an off-grid solar panel (PV) system using PVsyst for an existing operating swiftlet farm. Moreover, this paper discusses optimization of the off-grid solar PV system in term of shading, solar irradiation data, direction of sunlight and angle. Relative comparison and analysis on the cost involved, efficiency, losses, power consumption and etc were discussed. However, no physical installation or hardware is involved as well as no data collection.

Paper Organisation: We provide a brief review of the existing work, which can be related to estimation on off-grid solar PV system configuration and simulation. In Section III, we simulated a stand-alone swiftlet farm PV system based on the load requirement.

II. LITERATURE REVIEW

In this section, previous work and technicality related to PVsyst application were discussed and reviewed accordingly. PVsyst was used back in 2015 where Najah et. Al reported on his simulation study on factors that can affect the design and sizing of components in the PV system in an off-grid system in Hilla, Iraq with the GPS of coordinate 32.47° latitude and 44.41° longitude [5]. In his study report, the estimation and sizing of the solar PV system, the parameter of the selected components were thoroughly investigated and optimized. These outputs served as an added references and guidelines to design and estimate the sizing of the solar PV system. It can also avoid the over and under-sizing the solar PV system in simulation work and ensure adequate, reliable, and economical system design.

Shenawy et. al reported in his study on the stand-alone solar PV system for a household about 50 m^2 surface area in rural area situated in Shalateen, Egypt [6]. He reported a workable result for the stand-alone PV system in the rural area and taking into account factors such as geographical data, solar irradiation data, load requirement, and system configuration. This study also discussed the cost feasibility of the system such as remote area and economics analysis in terms of life cycle cost (calculated $3079) and electricity unit cost ($0.201/kWh). Therefore, it can used as guideline to analyse the cost of the system further to do the optimization. Along the line, Srivastava and Giri et al. reported on the utilization of PVsyst in design of grid connected PV System back in 2017 [7]. In this paper, the authors successfully estimated power generation of 901.44 MWh of energy in a year through grid connected PV system for Madan Mohan Malaviya University of Technology (MMMUT) using PVsyst. Meanwhile, Alnoosani et. al presented the design and simulation of a solar PV grid-connected electricity generation system of 100MW capacity in Umm Al-Qura University using PVsyst as well [8]. Both articles managed to outline the optimum operation and could potentially help to minimize the annual electricity and minimize the cost of supplying electricity to the power generation facilitates using PVsyst. These inputs provide a promising outlook which included important criteria such as site study location data, solar irradiation data and system configuration based on the load requirement.

Ali et. al reported in a conference proceeding on the detailed guidelines and technical considerations needed in the design process of a solar PV system for an off-grid PV system [9]. Selection of appropriate site/location and the sizing of the different components of solar system (PV panels, charge controller, storage batteries, inverter, and other equipment such as cables etc.) based on the load energy demand to design and install the solar PV system were extensively discussed. These inputs are useful for this works in estimating and designing the sizing of the PV system depends on the parameter of the components before the simulation. Alkhalidi and Hussain et. al reported on their work related to design an off-grid PV solar system that can cover 100% of electricity demand about 5.926 kWh/day using the off grid solar PV system on a tilted rooftop to provide the rural remote commercial purposed shelter throughout a year [10]. In this study, studies involving the tilt angle of solar array, geographical data, load requirement, system configuration, and sizing of components in the system were carried out. It also included the cost analysis and performance in the result and findings. Ballaji et. al described a design of independent housetop or rooftop solar PV system to supply a continuous and uninterrupted power to the load in India [11]. The article discussed on the framework about the sizing of solar PV system and system configuration based on the load demand energy and the characteristics of the components in the system. This study also involved analysis on economic investigation and costing with utilizing the System Advisory Module. From the result and finding, a good example for sizing the solar PV system on the theoretical work were presented but the losses such as shading factor and energy loss during the simulation were not taken into account.

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III. BACKGROUND & METHODOLOGY

1) Site Study Location and Solar Irradiance Weather Data

For this case study, a study site location located at the outskirts small town of Bintangor located in the middle coastal region of Sarawak was identified with corresponding GPS coordinate of 2.168260, 111.641667 or 2°10'05.7"N 111°38'30.0"E as shown in Figure 1. This study site is selected based on the intention of the operator to explore of the feasibility of switching from power-grid connected swiftlet bird farm to fully stand-alone PV solar system swiftlet bird farm. In addition, this location is also in proximity to coastal area which is the natural habitats of the swiftlets. For this study in PVsyst, the data used are based on Meteonorm 8.0 database [12]. Meteonorm 8 database is an open-access irradiance database and allows access to historical time series of irradiation, temperature, humidity, precipitation, and wind based on a specific location identify by GPS coordinates. Solar Irradiance data is primarily important for this project and should be included in all phases of design and load estimating.

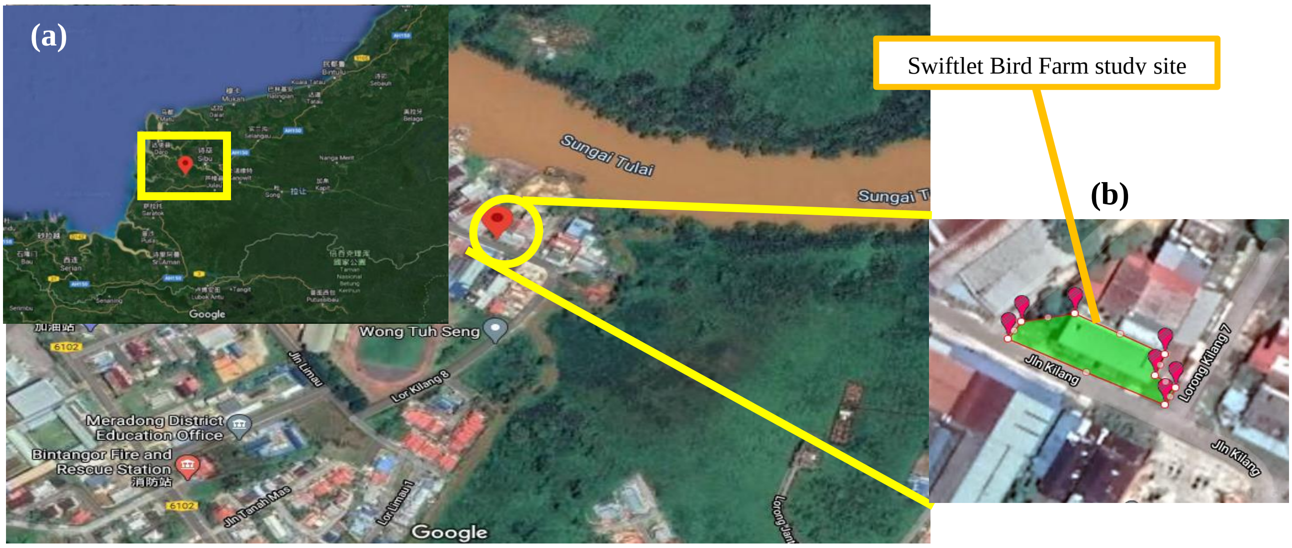

Figure 1: Study site location of swiftlet farm with inset images showing (a) Satellite view of the location in Sarawak (capture from the Google Map) and (b) Zoomed view of the selected location (GPS coordinate of 2°10'05.7"N 111°38'30.0"E)

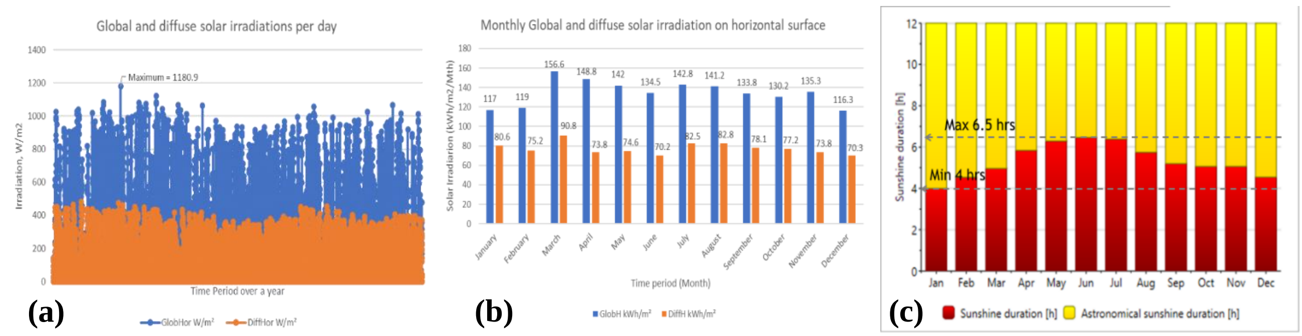

Figure 2: Crucial Solar Irradiation data extracted from Meteonorm 8.0 database using PVsyst simulator at the study site [12-16]. (a) Recorded daily global solar irradiation and diffusion, (b) Monthly global and diffuse solar irradiation on horizontal surface throughout a year and (c) Average monthly sunshine duration over a period of 12 months.

2) Load requirement of Bird Nest Farm

For this case study, in order to design the off-grid solar PV system, the load profile or consumption is needed. The inputs and preferences in term of energy loads from the company were taken as a reference which will provide basis simulation baseline for this study. The load study also in-corporates additional relevant appliances that ideally required for higher bird nest outputs. The simulation parameters of the appliances are based on the operating requirements from the bird nest farmhouse as shown Table 1.

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Table 1: Company's preferences in term of electrical loading requirement for this case study

Units	Components	Daily Used, Hours	Power, W	Daily Energy, Wh
4	Humidifier, NESTPRO HM7500, 1/6 HP (100W)	0.25	100	100
5	Fluorescent light, T5 Daylight, 4 Feet (1.22m) (Outside the building)	12	36	2160
120	Water Resistant Tweeter, HP4000 GW SWIFTLET, 3″ x 7″ (0.0762m x 0.1778m) (Inside the building)	24	25	72,000
6	Light commercial Air-conditioner, Midea DC Inverter 4-Way Cassette, 1.5HP (960W)	24	960	138,240
24	Water Resistant Tweeter, HP4000 GW SWIFTLET, 3″ x 7″ (0.0762m x 0.1778m) (Outside the building)	13	25	7,800
4	Silent Ventilating Fan, 12" (0.3048m) with air flow 960m3 / hrs	24	125	12,000
2	4 Channel Professional Swiftlet Amplifier, NESTPRO BS12 with USB repeat function	24	40	1,920
Summarized Power Peak used in Daily (Min – Max)			9,220 - 10,520 W	
Summarized Total energy of used in Daily (Min – Max)			203,772 - 234,220 Wh	
Summarized Total Units used in a Month (Min – Max)			6,113.16 - 7,026.60 kWh	
Summarized Energy used in yearly (Min – Max)			73,357.92 - 84,319.2 kWh	

Based on above details, an off-grid bird nest farm solar PV system was designed/estimated using PVsyst software as well as related calculations.

IV. PROPOSED SYSTEM DESIGN: PLACEMENT OF PV PANELS AT THE STUDY SITE

The structural dimension of the study site building is 48 ft x 20 ft x 36 ft (Length x Width x Height). In order to determine the best placement for the panels, a proper assessment of the PV panels is required to avoid any situation that may cause additional losses such as obstruction from sun irradiances, total surface area, poses no danger to public and etc. Therefore, visual inspection was first conducted to find the best possible placement location that might provide the best performance for the solar system. In this study, all simulations were conducted based on "shadow mode" which is referring to PVsyst simulation that takes into the account of irradiance losses caused by shadows or beam linear losses due to movement of the sun from East to West for the whole day. For this purpose, corresponding 3-dimensional drawing based on the current study site was drawn as per scale and used for all analysis and study. Figure 3 shows the overall design drawing as per scale based on the current study site in PVsyst software. On the other hands, Figure 3(a), 3(b) and 3(c) narrates the top view, cross-sectional view and front view respectively of the proposed placement and arrangement of all PV solar panels at the study site. The total surface area occupied by panels for red color region are 14.76 m (length) and 4.19 m (width); the green region are 28.88 m (length) and 1.09 m (width). For the rooftop of building, the length of blue region are 24.76 m and width of panels are 1.09m; while the length of purple region are 3.67 m, and the width of the panels are 1.09 m.

A total of 252 panels estimated are to be installed and being modulated accordingly based on total surface area available and different grouping with unique colour (red, blue, purple and green) coding. The red colour coded panels are placed in the ground while the green colour coded panels are both in the ground and in the rear wall of the building. Meanwhile, the blue and purple colour coded of solar panels are placed accordingly on the rooftop of the building. The total amount red color of solar panels are 28 and arranged in 2 rows in the left-hand side of the bird nest farm with each row has 14 panels. The amount of green color of panels are 140 modules and there are 5 rows of panels on the ground and 5 rows of panels are on the front wall of the building, each have 14 panels in a row. There are 7 rows of the blue color of panels on the rooftop of the building and total of 84 panels each 12 panels in a row. All panels were placed of tilt 60° on the surface without include the angle of the rooftop (12°) or on the wall which can refer to Figure 4.7. The spacing between each panel as the following, the spacing of each module in red color coded are 3 m. Meanwhile, the spacing of the green color panels (ground) are 1.5 m. For the front wall of the building, the spacing of panels are 1.9 m and lastly, the blue color panels of the spacing between are 0.95 m. During designation of the solar panels, the orientation of the plane tilt of 60° and azimuth of 26° is specified. There are also represent the angle of install for solar panels and the buildings. This is needed to consider as a parameter due to the orientation will affect the shading factor and it is important information for the installation in practice way. The azimuth angle (26°) is estimated on the satellite view from Google Map which make the same direction of the North. Due to the limitation of the software, all the color coded of planes tilt are set as 60° (no include the certain angle on the rooftop) because the PVsyst cannot set multiple angles of the plane in the drawing and need to consider the installation angle. In addition, the solar panels not only install on the rooftop and also install on the wall of the bird nest farm if in practical way

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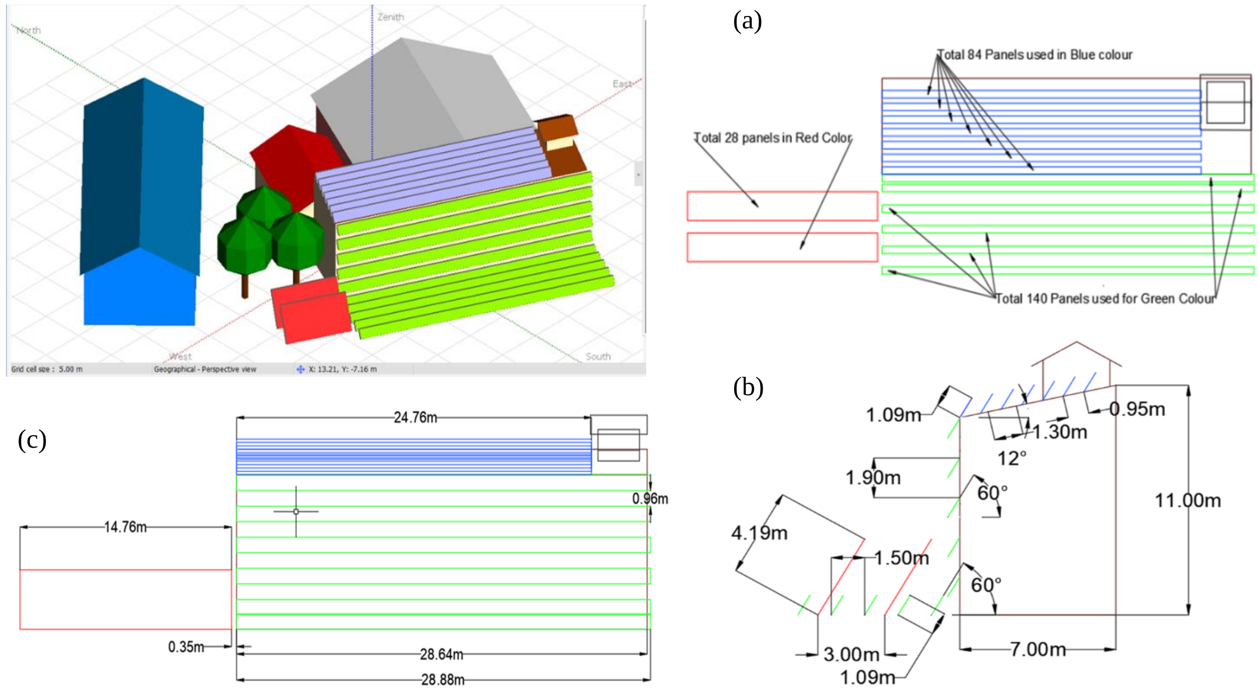

Figure 3: Overall illustration of panels' placement and shadow drawing in the PVsyst simulation software with insets (a) Top view of the proposed placement of panels at the current study site, (b) Cross sectional view of design, and (c) Front view of design.

V. ESTIMATION OF SYSTEM PARAMETERS

Based on the company's requirements as well as proposed panel system design, several parameters' calculation were carried out and summarized in this section as in Table 2 below.

Table 2: Corresponding estimation of Solar panel arrays, charge controller, battery banks and required inverters as per operative electrical loading in Table 1.

Section	Components	Values Estimation
Solar Panels	SUNPOWER with model SPR-X21-470-COM (470W, 77.6V, 6.06A) [13]	$\text{Required Energy, } E_r = \frac{\text{Daily average energy consumption, E}}{\text{Product of component's efficiencies, } \eta_{overall}} = \frac{234{,}220 \text{ Wh}}{0.8} = 292{,}775 \text{ Wh/day}$
		$\text{Peak Power, } P_p = \frac{\text{Daily energy requirement, } E_r}{\text{Minimum peak sun} - \text{hours per day, } T_{min}} = \frac{292{,}775}{4} = 73.193 \text{kW}_p$
		$\text{Total Current } I_{DC} = \frac{\text{Peak Power, } P_P}{\text{System DC Voltage, } V_{DC}} = \frac{73.193 \text{kW}_p}{48 \text{V}} = 1{,}524.87 \text{ Amps}$
		$\text{Number of Parallel modules, } N_p = \frac{\text{Whole module current, } I_{DC}}{\text{Rated current of one module, } I_r} = \frac{1{,}524.87 \text{A}}{6.06 \text{ A}} = 251.62 \approx 252 \text{ units}$
		$\text{Number of Series modules, } N_S = \frac{\text{System DC Voltage, } V_{DC}}{\text{Module rated voltage, } V_r} = \frac{48 \text{ V}}{77.6 \text{ V}} = 0.619 \approx 1 \text{ uni}$
Charge Controllers		$\text{Rated Current of Voltage controller, } I = I_{SC} \times N_p \times F_{safe} = 6.45\text{A} \times 252 \text{ units} \times 1.25 = 2{,}031.75 \text{ Amps}$

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	Victron SmartSolar MPPT 250/100, 48V, 100A [14]	$N_{controller} = \frac{I}{\text{Amps Each controller}} = \frac{2{,}031.75\,A}{100\,A} = 20.3175 \approx 21\ units$
Battery Bank	Sunpower VL OPzS 2-4700 with the capacity of 3488 Ah [15]	$E_{safe} = \frac{\text{Energy storage required}, E_{rough}}{\text{Maximum Depth of Discharge}, MDOD} = \frac{936.88\text{kWh}}{0.6} = 1.561\text{MWh}$
		$\text{Total capacity of Battery}, C = \frac{E_{safe}}{\text{Rated Voltage of each battery}, V_b} = \frac{1.561\text{MWh}}{2\text{ V}} = 780{,}733.5\text{ Ah}$
		$N_{batteries} = \frac{C}{\text{Capacity of each battery}, C_b} = \frac{780{,}733\text{ Ah}}{3488\text{ Ah}} = 223.83 \approx 224\text{ units}$
		$\text{Total number of batteries in series}, N_s = \frac{Voltage\ DC\ System, V_{DC}}{V_b} = \frac{48\,V}{2\,V} = 24\ units$
		$\text{Total number of battery bank in parallel}, N_p = \frac{N_{batteries}}{N_s} = \frac{224\ units}{24\ units} = 9.333 \approx 10\ units$
Inverter	MPP Solar PIP-11048LC [16]	Based on the estimation on Table 1, the system required maximum peak power of 10520 W to operate at the same time

VI. RESULTS & DISCUSSIONS

This section presents an overview of the main simulation results, followed by a discussion that contextualizes these findings within existing literature and the research objectives. The simulation results and accompanying discussion cover various parameters such as costs, efficiency, losses, and power consumption, as analyzed through PVsyst simulation software as in Figure 5 respectively. Figures 5(a) to 5(g) illustrate key outcomes obtained from PVsyst. Specifically, Figure 5(a) summarizes the proposed bird nest farm's load entries, based on all operating appliances listed in Table 1, showing a total monthly load requirement of 7,029.6 kWh and a daily load requirement of 234,320 Wh/day. From these data, the estimated annual load is approximately 84,355.2 kWh. Figure 5(b) provides further details, showing characteristics such as the number of required solar panels, charge controllers, batteries, and total power generation by the solar panels. For this setup, 252 modules are needed, achieving a nominal power output of 118 kWp under Standard Test Conditions (STC). Figures 5(c) and 5(d) then depict the simulated peak power consumption of the system on both daily and monthly scales, indicating a maximum daily power demand of 10.52 kW and a minimum of 9.22 kW.

Shading loss factor which is one of the key parameters was also being included and studied in this simulation. Figure 5(e) illustrates the shading loss factor over a day, from 6 a.m. to 6 p.m. This figure depicts how shading changes throughout the day to support optimization of the solar PV system. The shading factor starts at 1.0 around 7 a.m., as sunlight initially shines on the rear side of the building and solar panels due to the sun rising in the east. As sunlight direction shifts, the shading factor decreases, reaching zero by approximately 1:30 p.m., then gradually increases to 0.5 by late afternoon when the sun moves west, causing partial shading that reduces solar panel irradiation. Next, for the simulated energy PV normalized production result over a year as shown in Figure 5(f), color coding indicates energy distribution: blue represents unused energy when the battery is fully charged, purple indicates collection or PV-array losses, green shows system and battery charging losses, and red denotes energy supplied to the user. Based on the results, on average, daily unused energy is 0.09 kWh, collection losses are 0.88 kWh, system and battery charging losses are 0.29 kWh, and energy supplied to the user averages 1.72 kWh per day.

In assessing the actual energy produced by the proposed system, the Performance Ratio (PR) which is shown in Figure 5(g) summarized the ratio between the energy effectively utilized and the energy that would have been produced if the system operated continuously at its nominal efficiency under Standard Test Conditions (STC) needs to be monitored carefully. This ratio, which reflects system efficiency in real-world conditions, is defined by the IEC EN 61724 standard. Technically, the Performance Ratio (PR) by the PVsyst software is defined as the ratio of system yield (Y_f) to reference yield (Y_r), measures overall system efficiency. Y_f refers to the system's daily useful energy (in kWh/kWp/day), while Y_r represents the ideal array yield per nominal power at Standard Test Conditions (STC), as specified by the manufacturer.

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Solar Fraction (SF) indicates the proportion of user energy demand met by solar energy, calculated as the ratio of E_{Sol} (energy supplied to the load) to E_{Load} (total user energy demand). The average PR is 0.579, while the average SF is 0.871. The simulated PR value is moderate but relatively on the lower versus the well-positioned system which has values between 0.7 to 0.9. The low PR value mostly contributed by factors such as shading, temperature losses, system design, or inefficiencies in inverters and cables. It suggests there might be room for improving aspects like shading reduction or equipment optimization to enhance system performance. On the other hand, the simulated Solar Fraction (SF) parameter reflects the proportion of the load that the solar energy system can meet, where a higher value indicates greater self-sufficiency. An SF of 0.871 is quite favorable, indicating that the PV system supplies 87.1% of the load demand, minimizing reliance on other energy sources. This is beneficial for sustainability and cost savings.

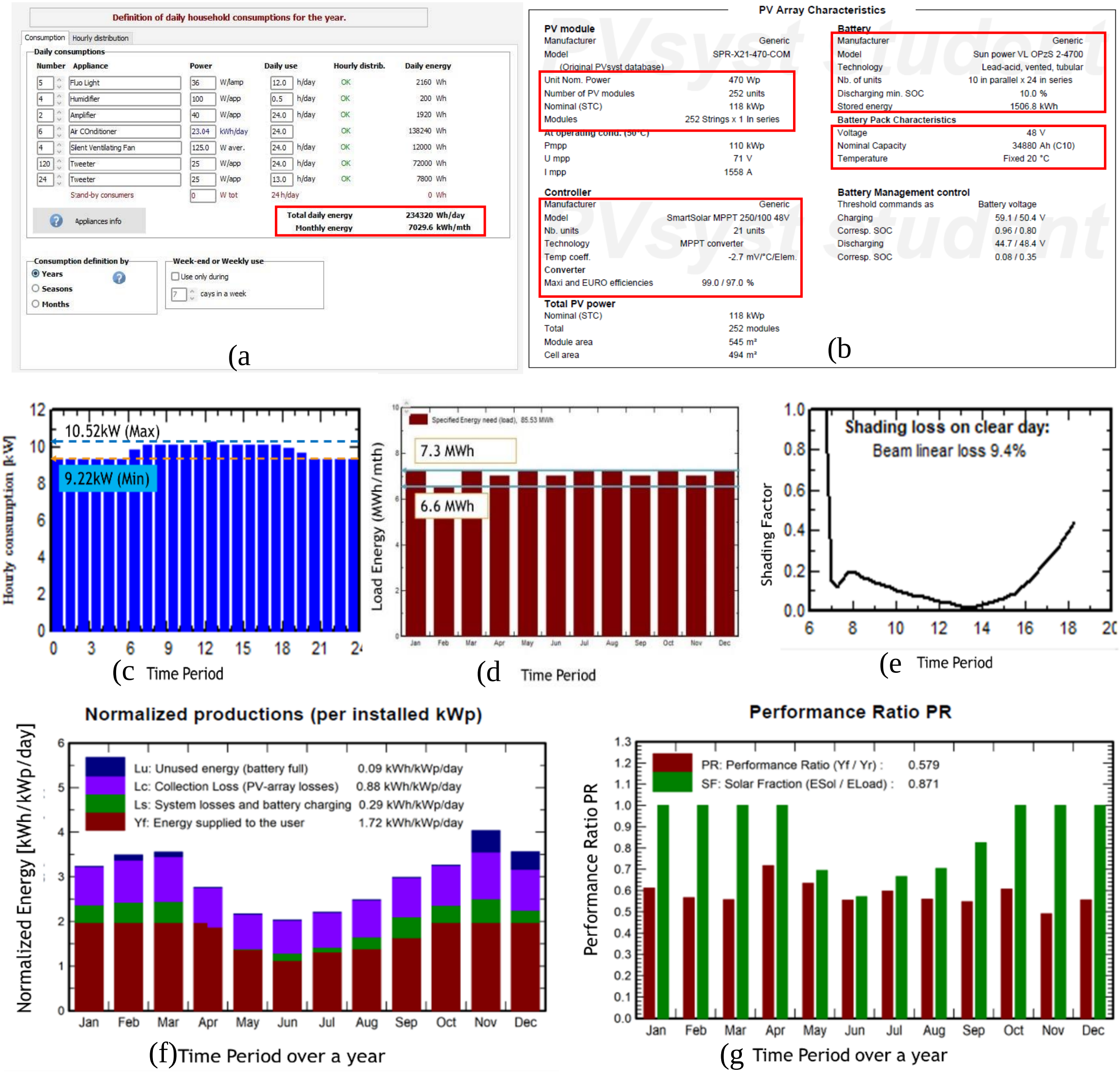

Figure 5: Simulation results capture from the PVsyst. (a) Load entries via PVsyst, (b) Characteristics of the PV proposed array, battery, and charge controller, (c) Daily peak power consumption, (d) Monthly Load energy required, (e) Simulation curve of the Shading Factor in single day captured, (f) Normalized production result over a year, and (g) Performance ratio (PR) and Solar Fraction (SF).

Meanwhile Table 3 depicts collectively the data that could provide insight into system performance, energy efficiency, and how well the PV system meets user demand. GlobHor (Global Horizontal Irradiation) measures the total solar irradiation received on a horizontal surface over a specific time period. This is the raw energy input before considering angles, shading, or panel orientation. GlobEff (Effective Global Irradiation) shows the effective irradiation after corrections for the IAM (Incidence Angle Modifier) and shading. E_Avail (Available Solar Energy) represents the total usable solar energy after adjusting for panel efficiency losses. Next, EUnused (Unused Energy) indicates the excess energy generated by the system that cannot be used or stored, typically occurring when batteries are fully charged or demand is low. E_Miss (Missing Energy) suggests the energy that the system could not supply to the load due to insufficient generation. This often happens when solar energy production is lower than the demand. Moving on, E_User (Energy Supplied to the Load) signifies the energy directly used from solar generation. E_Load (Energy Need of the User) refers to the total energy required by the load (the baseline energy demand). Lastly, SolFrac (Solar Fraction) measures the proportion of total load demand met by the PV system. Higher solar fractions indicate more reliance on solar energy and greater self-sufficiency.

Table 3: Simulated Working Parameters based on the proposed design versus weather monthly for a year duration

Balances and main results								
	GlobHor (kWh/m²)	GlobEff (kWh/m²)	E_Avail (kWh)	Eunused (kWh)	E_Miss (kWh)	E_User (kWh)	E_Load (kWh)	SolFrac ratio
January	117	81.71	8321	1	0	7264	7264	1
February	119	79.27	8110	381	0	6561	6561	1
March	156.6	87.46	8966	355	0	7264	7264	1
April	148.8	62.2	6255	0	0	7030	7030	1
May	142	47.85	4646	0	2219	5045	7264	0.695
June	134.5	42.87	4120	0	3019	4011	7030	0.571
July	142.8	48.95	4772	4	2421	4843	7264	0.667
August	141.2	56.79	5643	3	2155	5109	7264	0.703
September	133.8	69.94	7083	1	1228	5802	7030	0.825
October	130.2	81.58	8286	7	0	7264	7264	1
November	135.3	99.78	10251	1675	0	7030	7030	1
December	116.3	91.6	9295	1422	0	7264	7264	1
Average Year	1617.5	850	85748	3851	11041	74485	85527	0.871

From the simulation results as well, losses were observed due to various reasons. the irradiance loss observed stands at 18.36%, while PV losses due to irradiance level account for an additional 2.31%. Energy loss due to unused energy when the battery is fully charged is 4.25% (or 3.9 MWh/year), and missing energy amounts to 12.91% (or 11.04 MWh/year). Additionally, the energy supplied to the load, totalling 74.49 MWh/year (depletion of 11Mwh/year). Depletions could be due to factors such as lower irradiance, suboptimal panel angles, shading, and storage losses [17]. Based on this study, addressing a 11 MWh/year depletion might involve strategies like increasing the solar panel array and reducing system inefficiencies as part of optimization works.

VII. CONCLUSION

In conclusion, a fully off-grid solar PV system was designed and proposed for a bird nest farm using PVsyst, based on estimated load requirements by the industrial partner. The proposed system aimed to meet an energy consumption of 85.527 MWh/year, with initial simulations indicating it would supply 74.697 MWh/year, leading to a shortfall. The estimated solar panels required are 252 units, the batteries required are 240 units, the charge controllers required are 21 units. Optimization are required with focus on improving panel efficiency, reducing irradiance and converter losses, and minimizing unused energy, ultimately meeting the load demand.

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