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DESIGN OF 2.O KW SOLAR PHOTOVOLTAIC (PV) SYSTEM WITH MICROCONTROLLER BASED POWER TRANSFER SWITCH

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ABSTRACT

This paper presents a design a 2.0kW solar photovoltaic (PV) system with a microcontroller-based power transfer switch designed for the intended 980W load of the third floor of the three-story building. The study determined that a 2.0 kW solar PV system can generate 8.92 kWh/day, enough for the 7.840kWh/day daily requirements based on the simulation using PVsyst. Four units of PV module were used for the design, with an individual 500W power rating. Four units of PV module were used for the design, with an individual 500W power rating. For the Microcontroller-Based Power Transfer Switch, an ACS712 current sensor was used to monitor current. The microcontroller was programmed to accept input from ACS712 and send a digital signal to the relay to change the power source. PVSYST simulates a generation of 3254 kWh/year. Interpreting the system output in kWh/day only the month of December was not able to reach the 7,840 Wh/day power demand while the rest other months averaging 8.92 kWh/day enough to energized 8 hours operation.

KEYWORDS: Solar photovoltaic (PV) system, Microcontroller-based power transfer switch, Current sensor, and PVSYST Simulation.

1. INTRODUCTION

For many students and teachers across the Philippine archipelago, energy poverty is a challenge faced every day both at home and at school (Mendoza, et al., 2019). As a consequence, teacher manually write lessons on the chalkboard, which is a very time-consuming and less motivating teaching approach. An actual case reported that some students from Bayambang, Ilocos Region were unable to attend online classes when there was a sudden power interruption, and the internet signal became poor because of towers nearby not operating (Philstar Global Corporation, 2020). The absence of electricity significantly limits the instructional materials used by the teachers. Without electricity, both teachers and students will miss the latest and updated technology that will have a new impact on the teaching-learning process. Also, they can't access online resources such as videos and other multimedia sources in their classrooms as valuable methods for instruction. As a result, teachers failed to provide their students with the quality of education they deserved. Lack of electricity also makes the daily operation procedure complicated. School administrators are required to keep manual documentation of student and faculty grades and attendance rates on paper instead of keeping a reliable, online record.

A good solution to the energy poverty in the Philippines would be the initiative to install solar panels in certain schools experiencing electricity problems (Thrive Solar Energy Philippines, 2016). The solar panels would give the schools solar energy that generates enough energy to keep the blackouts from occurring and even more. This would lower the number of monthly bills I have to pay to get electricity to power the school buildings. A short-term goal for this solution is to generate enough energy to keep blackouts from occurring. The electric bill may be reduced, and the return on the initial investment may be felt for a few years.

Trento National High School, one of the secondary schools in Agusan del Sur located along the Maharlika Highway, Poblacion Trento, Agusan del Sur, a first-class municipality, was dependent on the line of Agusan del Sur Electric Cooperative (ASELCO). That means the school will also experience power failures when the supply of ASELCO trips off. As a consequence, daily operations in the school will be affected, and some teaching facilities, such as computers, will not be available during classes and different transactions.

The paper is focused on the Design of 2 kW Solar Photovoltaic (PV) System with Microcontroller Based Power Transfer Switch. This study was limited to the design of a 2 kW solar PV system for an identified load using PVSyst and simulation of power transfer using Proteus. The location of the designed system is on the third floor of the three-storey building of Trento National High School. Lights, electric fans, and flat-screen televisions will be only considered as active electrical loads. It also includes a cost estimate for the design.

2. OBJECTIVE OF THE STUDY

The primary goal of the study was to design a 2.0 kW solar photovoltaic (PV) system with a microcontroller-based power transfer switch for Trento National High School electrification. Specifically, this study aims to:

1. Determine the energy load profile of the building and the solar resource (irradiance) of the area.

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

2. Design a solar PV system in terms of the following:
a) Number of PV modules b) Inverter sizing
c) Wiring diagram
d) Structural design
3. Design an automated transfer switch (ATS) using a microcontroller.
4. Simulate daily generation using PVSYST

3. METHODOLOGY

Methods on Designing of Solar Photovoltaic (PV) System

Site assessment

The first step to determine how the design works and how the panel was placed and positioned. The following concepts during site assessment was the guide for the design:

1. Shade Analysis: Shading will result in solar panels decreasing the maximum power that can be provided. Neighboring buildings and trees, local cloud condition and adjacent solar panels are several factors contributing to this problem, thus selection of area of placement was crucial during the design.

2. Sun hours: In determining how much radiance will be required to generate the needed output wattage. This parameter provides the knowledge of the number of hours an area will receive maximum sunlight (Franklin, 2017). Many websites are available to give the number of sun hours in the area, and useful to be used for the design.

3. Tilt Angle: Tilt angle is the setting of the panels one needs to have to get the maximum radiance. Ideally the tilt angle is the latitude of the geographic location. It is suggested to have adjustable panel frames as the sun hours keep changing with respect to the tilt in winters and summers. Hence for any area a specific tilt angle is calculated to get the maximum radiance throughout the year for a fixed panel.

Requirement Specification

Energy Calculation

The wattage of individual load was identified and added to get the total wattage to be powered using solar PV system. Identified load was tabulated according to the room assignment. Total wattage per room and total required wattage was computed.

Panel Sizing

International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

Solar PV modules reduce output voltage when the temperature along the panels reach higher than 25 degree Celsius and because of the higher temperature in the field, the utilization of PV modules should consider a rated tolerance in the design. This module often has a tolerance rating of +/-5%. The output power of the PV module significantly reduces when the temperature increases. In actual operation of this PV module, the temperature may range from 50-75 degree Celsius which significantly affect the output power. Crystalline modules have a reduction factor of 89% based on this temperature ranges endorsed by Clean Energy Council CEC. The accumulation of dirt and dust over a period had also provided a factor in the reduction of power output by blocking the light energy that supposed to enter the PV module. The power output was reduced to 93% because of this constraint. The peak power output of the solar PV module array was regularly less than the sum of the rated individual modules. The difference was the result of the inconsistent performance of one module to another which was termed as the module mismatch, which had amounted to 2 percent loss in system power. Losses of power could also be due to heavy resistance in the system wiring. These losses are difficult to minimize under 3% for the system. A practical reduction had been taken for these losses which give efficiencies under 95% or 0.95 of the power output. Another efficiency loss was caused by conversion from direct current to alternating current which was usually applied for large power-consuming devices. The conversion of DC to Ac was done using an inverter which introduces loss by the heating elements that proceed along the process of power inversion. Some power was lost in the process. Generally used inverters that applied in household PV system have 92% up to 94% peak productivity measured under factory conditions. In an actual application, the overall dc-to-ac will result in conversion efficiencies for about 90%. Summing all these factors had resulted in this formula,

$$Po=(1-le) \qquad \textbf{Equation -1}$$

where ***Po*** was the estimated final power output and ***Pr*** was the rated power of the panel, while ***le*** refers to the summation of all the efficiency loss in the system and was determined to be 38 percent. Simplifying the equation in eEquation 2 from equation 1 may result in,

$$Po=0.62Pr \qquad \textbf{Equation-2}$$

The equation 2 was used to calculate the actual power output of the solar panel.

Inverter

The output of solar arrays was direct current in form, loads energize using alternating current and power from the solar arrays can be used by using inverters that convert DC from PV module to AC it will ensure that the cycle of alternating current cycles is 60 cycles, reduce voltage variations and ensure that the

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

condition of the AC waveform is suitable for the application. Most system-connected inverters can be introduced externally, and most of the off-grid inverters are not weather-resistant. The design will consider inverters that can handle battery-less that the input from solar charge controller will be directed to inverter. For example, if the system is designed to generate 2000 Watts at a voltage level of 24 V then the inverter selected should be rated 24V, 2000 Watts (Alternative Energy, n.d.).

Photovoltaic Controller

Since the design was not involving battery the photovoltaic controller main function is to feed the inverter with regulated DC voltage match or working with the inverter. Pulse width modulation type of controller was considered on the design to match the working voltage of inverter.

Design of Control System

The automation of the system uses the AC current sensor to monitor the current of the present load, the microcontroller will determine if the current is over with the set value, and it will trigger the relay to switch from solar PV source to grid.

4. RESULTS

Site Assessment

Figure 2 shows the building subject by the design, during ocular inspection it is observed that shading factor is negligible because of the height of the building compared to its neighboring structures, the roof is approximately inclined 22 degrees.

Figure 2. Three Storey SHS Building of Trento National High School

Using igismap.com bearing/azimuth was determined to be 70.49 degrees and these values were used as input factors in PVsyst simulation.

International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

Source: igismap.com

Figure 3. Satellite view of Trento National High School Campus

Intended Load Profile Estimate

Table 1. Intended Load Profile

Load	Quantity	Duration	Wattage	Total Power
Ceiling Fan	8	8 Hours	60 Watts	480 Watts
Fluorescent Light	8	8 Hours	30 Watts	240 Watts
LED TV	4	8 Hours	65 Watts	260 Watts
Total				980 Watts

Daily Power Demand = Peak Power Demand x Duration
Peak Power Demand = 980 Watts x 8 Hours
Daily Power Demand = 7,840 Wh/day

Table 1 leads us to the daily power demand of 7,840 Watt-hours a day or a peak power demand of 980 Watts. Equation 2 was used to estimate the size of the PV system, which was determined to be 1.58064 kW, sizing up to 1.6 kW.

Po=0.62Pr

(980 Watts) = 0.62Pr

Pr = 1,580.64 Watts

This 1.6 kW PV system size value was simulated using PVsyst, which only yields a yearly average of 7.14kWh/day system output, which is not enough to cover the demand of 7.84 kWh/day. From the simulation result, the design was increased to 2.0 kW resulting into 8.92 kWh/day system output, enough to cover 7.84 kwh/Day energy demand. Based on the result of simulation using PVsyst, the 2 kW Solar PV System will be used for the design.

Number of Panels and Wiring Connections

An estimated 2.0 kW design requires four (4) solar panels with a maximum peak power of 500 watts. The four (4) solar panels were combined in series connection. Figure 4 shows the wiring diagram connection of the design, starting by combining the four (4) solar panels in a series connection using an MC4 connector, and the combined panels were employed with 2-3.5 s.q. mm. grounding wire enclosed in a 15 mm diameter PVC pipe. The recommended power wiring to be used is 2-4 s.q.mm. PV cable enclosed with 15 mm diameter PVC pipe.

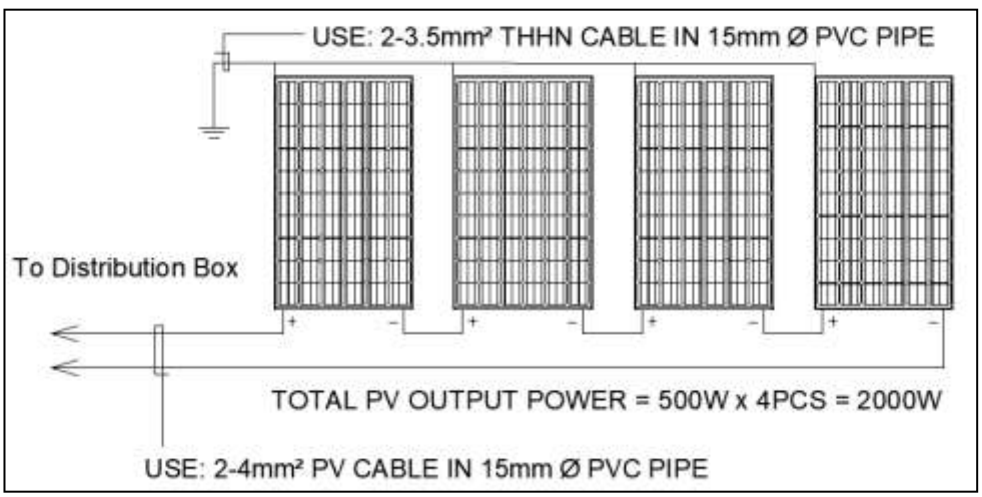

Figure 4. Solar PV Array Wiring Diagram

Microcontroller Based Power Transfer Switch Simulation

Solar PV System output is instantaneous and dependent on the intensity received from the sun. This project was designed without using batteries; thus, the output of solar panels was directly fed to the inverter. In this set-up, there is a high chance of possibility that the power produced is not enough due to the many

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

factors experienced by the solar panel. A microcontroller-based power transfer switch was designed using Proteus Electronic Simulation Software. Figure 14 shows the wiring connections for the automatic switching process. Solar power generated in every room of the building was connected to an ACS712 current sensor to monitor the total load current. Each room was equipped with high current double pole double throw relay to switch between solar PV source and utility grid.

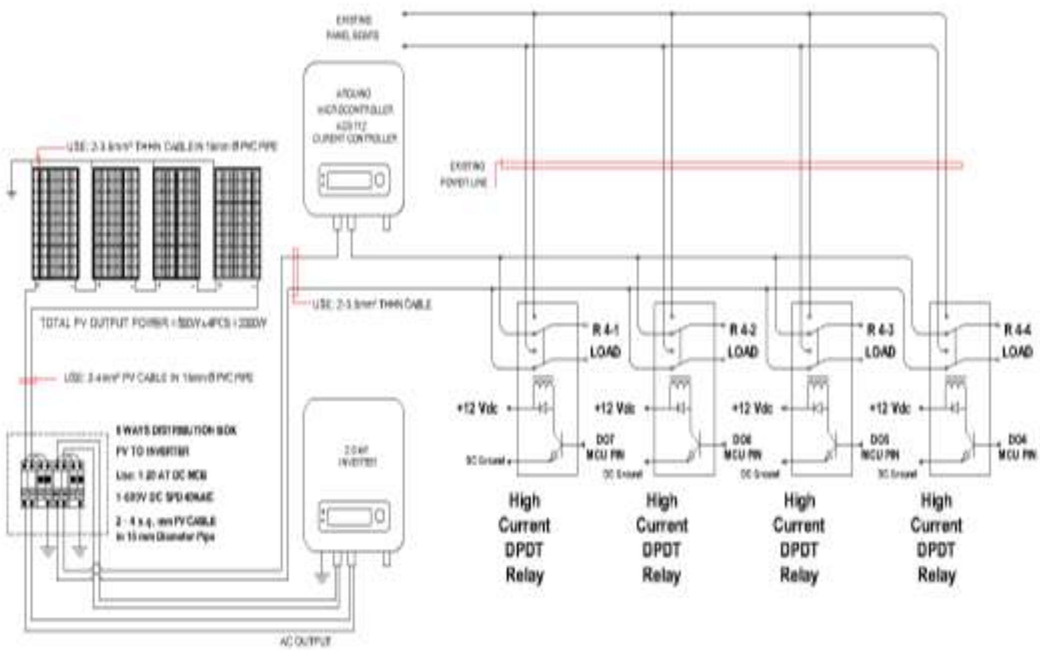

Figure 5. Switching Wiring Circuit

Table 2 shows the switching decision values code telling the relay what power source must switch to energize the load or what specific room has to be energized, and if the current draw by the loads is less than 4.5A and greater than 4.3A the logic will be true for the relay 1 to 4, in which room 1 to 4 is connected to the inverter. If the current draw by the loads is less than 4.3A and greater than 3.3A, the logic will be true for the relays 1 to 3, and low for relay 4, and that will transfer the source of room 4 to the grid. For every change of current level, switching of source is automatically executed by the relays to for the electrifications of rooms 1 to 4.

Table 2. Decision Values for Electrification

Current	Inverter	Grid

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

4.3A<Imp<4.5A	R1, R2, R3, & R4	
3.3A<Imp<4.3A	R1, R2, & R3	R4
2.3A<Imp<3.3A	R1 & R2	R3 & R4
1.3A<Imp<2.3A	R1	R2, R3, &R4
Imp <1.3		R1, R2, R3, & R4

Microcontroller Arduino with LCD, analog pin A0 is connected to voltage divider circuit which has a function to read the voltage level of the solar PV output from controller. Analog pin A1 is connected to the current sensor ACS712 which has a function to read the AC current draw from the load active.

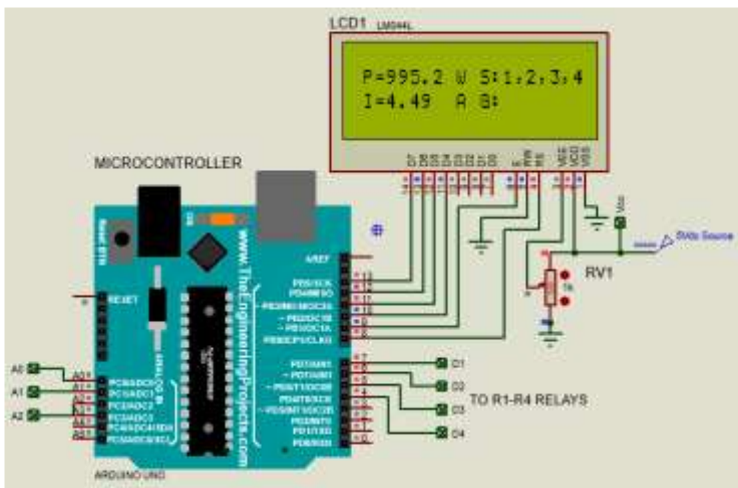

Figure 6. Arduino UNO Microcontroller with LCD

PVSYST Simulation

The work reported in this paper analyses the behavior of a 2 kWp photovoltaic system to either feed on-site electrical loads (a public institution, Trento National High School, located at southern part of Philippines, latitude 8.05 °N and Longitude 126.06 E°). The system simulation uses the PVSyst software with Meteonorm derived and measured climate information sets (ambient temperature, solar irradiation and wind speed). The agreement between the simulated and measured energy yield is analyzed including the evaluation of the optimal generation energy of the PV array, the energy that is fed into the network, the performance ratio, and the normalized energy generation per installed kWp. The PV system considered in this work generates 3254 kWh/year. Interpreting the system output in kWh/day only the month of December was not able to reach the 7,840 Wh/day power demand while the rest other months averaging 8.92 kWh/day enough to energized 8 hours operation.

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

Estimated Cost

Based on the latest prices canvassed the total project cost was about Php 97,795.00, with Php 11.9274 price per kWh, annual kWh demand of 1,638.56 kWh and Php 6,500.00 operational cost.

Table 3. Material, Shipping and Labor Cost Estimates

Description	Qty	Unit	Unit Cost	Amount
Equipment and Materials				
PV Modules, Mono 500W	4	Panel	8,800.00	35,200.00
PV Cable, 4 sq. mm.	20	Meter	95.00	1,900.00
PVC Pipe 15 mm Diameter	15	Length	100.00	1500.00
Elbow 15 mm Diameter	5	Piece	15.00	75.00
THHN, 3.5 sq.mm.	80	Meter	28	2,240
MC4 Connector, Pair	4	Pair	60.00	240.00
PV Railing, 2.3 Meters	4	Set	580.00	2,320.00
End Clamp 35 mm	4	Piece	40.00	160.00
Inter Clamp mm	6	Piece	400.00	240.00
L-Foot	12	Piece	700.00	840.00
Inverter, 2kW, 80V-600V	1	Unit	18,000.00	18,000.00
8 Way Distribution Box	1	Unit	550.00	550.00
20 AT DC MCN 2P	1	Unit	400.00	400.00
600 V DC SPD 2P	1	Unit	830.00	830.00
20AT AC MCB	1	Unit	200.00	200.00
385 V AC SPD 2P	1	Unit	430.00	430.00

Grounding Lug	4	Piece	40.00	160.00
Cable Duct, 2 Inches	2	Meter	300.00	600.00
Arduino Uno	1	Unit	500.00	500.00
LCD Module	1	Unit	500.00	500.00
ASC712 Current Sensor	1	piece	400.00	400.00
High Power Relay, DPDT	4	Piece	1,500.00	6,000.00
Utility box	12	Piece	25.00	300.00
Resistors (1k-100k)	4	Piece	5.00	5.00
Capacitor (1nF)	2	Piece	10.00	10.00
Diode (Zener 1N4734A)	1	Piece	150.00	150.00
Diode (1N4001)	1	Piece	45.00	45.00
Transportation Cost	1	Shipment	4,000.00	4,000.00
Labor for Panel Installation	1	Contract	20,000.00	20,000.00
Total Material & Labor Cost				**97,795.00**
Cleaning and Security	1	year	5,000.00	5,000.00
Facilities Insurance	1	year	1,500.00	1,500.00
Total Project Cost				**121,920.00**

5. CONCLUSIONS

The design for the alternative power which was in the form of solar energy system with a load profile of 7,840 Wh/day or 980W will lead to a size of 2kW solar PV system based on the simulation done using PVsyst with average of 8.92kWh/day output.

Using ACS712 Current sensor with Arduino microcontroller we can implement a system that can automate the transfer of power during failure of AC current, it was observed using proteus simulation software, the simulation can detect over current draw from active load, it can detect under and over voltage from the output of photovoltaic controller. The relay will be trigger at least one of failure condition will

ISSN: 2582-6271

Vol. 7, Issue.3, May-June 2026, page no. 01-12

be present.

The 2kW Solar PV system design has estimated a cost of Php 97,795.00 that includes module cost of Php 35,200.00, inverter cost of Php18,350.00 and transportation cost of Php 5,000.00. Maintenance cost every year is Php 6,500.00. PVSYST simulates a generation of 3254 kWh/year. Interpreting the system output in kWh/day only the month of December was not able to reach the 7,840 Wh/day power demand while the rest other months averaging 8.92 kWh/day enough to energized 8 hours operation.

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