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PAPER 27 - DESIGN MODIFICATION AND PERFORMANCE EVALUATION OF SOLAR PV SYSTEM AT AUTOCAD LABORATORY

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ABSTRACT

The AutoCAD Laboratory at Faculty of Engineering at Kano University of Science and Technology, Wudil (KUST Wudil) faced power supply issues due to an inadequate photovoltaic (PV) system. This paper presents a comprehensive overhaul, dimensioning, and implementation of an amended PV system in the Laboratory. A load analysis was carried out, revealing a daily requirement of 275.97 Wh, significantly surpassing the average power output achievable with the current PV system. Consequently, the PV system components were meticulously tailored to power the load adequately, with a surplus. The Ampere Hour Load Method guided the sizing, resulting in the inclusion of eight batteries (100 Ah, 12 V), ten PV panels (100 W, 12 V), one 80 A charge controller, and one 1.5 kW inverter, which collectively meet the load demand. Evaluation of both systems' performance from January to December 2022 revealed that the old system's struggle to generate sufficient power, with monthly averages ranging from 1750 to 2200 Watts, falling short of load requirements varying from 3800 to 4050 Watts. Conversely, the modified PV system consistently outperformed expectations, generating monthly averages ranging from 3850 to 4220 Watts, surpassing the load requirements and ensuring uninterrupted equipment operation. This success emphasizes the significance of appropriately sizing and designing renewable energy systems.

KEYWORDS: Photovoltaic (PV) system, load analysis, renewable energy, sizing of battery, inverter, charge controller.

1. INTRODUCTION

Energy is a necessity like food and water. Everything around us requires energy. Over the years there has been an increase in the earth's population which is directly proportional to the energy used as well. All the possible gadgets and equipment need some or the other kind of energy to function. With depleting fossil fuel reserves it becomes necessary to identify viable renewable energy resources that can decrease the dependency on fossil fuels (Bosshard, 2006; Seger, 2016). Solar energy is the most abundant form of energy available to us. It is approximated that 10000 TW worth of solar energy is incident on earth's surface in a day (Bosshard, 2006). According to a report, the world energy consumption in 2015 was 17.4 TW altogether (Seger, 2016). There has been a minimal increase in the energy consumption every year, approximately 1-1.5% annual growth.

The world's total energy consumption is expected to grow by 56% by the year 2040 (U.S. Energy Information Administration, 2013). To guarantee maximum performance and efficiency, PV system design incorporates a number of components and factors. Solar irradiance, panel orientation, tilt angle, shading analysis, battery storage, and system sizing are examples of design elements (Feng et al., 2017). To meet energy demand and maximize the use of solar resources, proper sizing and configuration are essential (Alghoul et al., 2019). Furthermore, new developments in PV technology, such as bifacial panels and smart inverters, present chances to raise system dependability and efficiency (Bashir et al., 2020).

The adoption of PV systems is influenced by a range of socio-economic, institutional, and policy factors. Studies have identified factors such as affordability, access to financing, awareness, technical expertise, and government incentives as critical determinants of adoption (Aderamo et al., 2020; Oseni et al., 2018). Additionally, community perceptions, cultural norms, and trust in technology play significant roles in shaping adoption behaviour (Adefila et al., 2019). The abundant solar resource in the region presents an opportunity for PV system adoption to diversify the energy mix and enhance energy access, especially in rural and underserved communities (Balogun et al., 2021). Studies have shown the economic viability of PV systems in Kano State, with potential benefits including

cost savings, job creation, and environmental sustainability (Abdulaziz et al., 2019). However, challenges such as limited infrastructure, regulatory barriers, and market fragmentation need to be addressed to unlock the full potential of PV adoption in the region (Oladejo et al., 2020).

The contribution of this work lies in its specific focus on addressing the challenges posed by an inadequate power supply in the AutoCAD Lab through the modification and optimization of a photovoltaic (PV) system. While there exists a considerable volume of related works on PV system design and implementation, this study offers a unique perspective by presenting a comprehensive redesign, sizing, and installation tailored specifically to the energy needs of the AutoCAD Lab at Kano University of Science and Technology, Wudil (KUST Wudil). By conducting load analysis and employing the Ampere Hour Load Method for sizing, this research ensures that the modified PV system effectively meets the lab's energy demands, thereby enabling uninterrupted operation of essential equipment for learning, teaching, and research activities. Furthermore, the evaluation of system performance over an entire year provides valuable insights into the effectiveness and reliability of the modified PV system compared to the previous setup. This detailed and context-specific approach adds significant value to the existing body of research on renewable energy systems, highlighting the importance of tailored solutions for addressing energy challenges in educational and research environments.

2. MATERIALS AND METHOD

The materials and methods used in this work are explained in this section. The materials used involved:

- i. Mono-crystalline Panel: these panels are made from a single crystal. Specifications: brand name: PRIME SOLAR, capacity: 100W/12V, size: 1200 × 540 × 30mm mm, quantity: 10
- ii. Deep Cycle Lead-acid Battery: Specifications: brand name: GSR Power Company India, capacity: 100AH 12V, quantity: 8
- iii. Inverter: Specifications: capacity: 1.5KW, quantity: 1
- iv. Charge controller: Specifications: capacity: 80A 12V/24V, quantity: 1
- v. Wire cable (solar cable 23 yards and electric cable 10 yards)
- vi. Change over switch
- vii. Circuit breaker

Moreover, the method adopted in this study was Amphere Hour Load, designed procedures and sizing of stand-alone system are detailed in this section. It also outlines the design process that must be completed before the purchase and installation of any PV system component. The process includes the following steps:

- Assessment /Evaluation of the Existing PV System Design in the Laboratory
- Design Consideration for the Modified PV system
- Sizing of PV System Components using Ampere Hour Load Method

2.1. Assessment /Evaluation of the Existing PV System Design in the Laboratory

Table 1. Shows Load evaluation and power consumption for existing PV System in the laboratory

Table 1. Load evaluation and power consumption for existing PV System in the laboratory

Appliances	AC (W)	DC (W)	Quantity (Number)	Wattage $AC \times 1.15$ (W)	Hours/Day	Days/Week	Daily Consumption of load (Wh)	Average Wh/day (Wh)
Projector	100	0	1	115	4	6	76.67	98.57
Fan	20	0	6	23	4	6	15.33	19.7
Computer	65	0	5	74.75	3	6	37.375	64.07
Bulbs	11	0	6	12.65	2	6	4.22	10.84

Highest AC loads in watts =100 W

Total AC connected in wattage at a time = $100 + (20 \times 6) + (65 \times 5) + (11 \times 6) = 611 \text{ W}$

Total watt-hour per day = $98.57+19.7+64.07+10.84 =193.18 \text{ Wh/day}$

Corrected watt-hour per day = $\frac{\text{Total watt-hour per day}}{\text{correction factor}} = \frac{193.18}{0.7} = 275.97 \text{ Wh/day}$

Total daily consumption of a load = $76.67+15.33+37.375+4.22 =133.595 \text{ Wh/day}$

The existing solar PV system uses sun hours as 10 hours, whereas the actual sun hours in Kano was highest in October with average sun hours of 9 hours 48 minutes daily, and lowest in August with average sun hours of 6 hours daily. Hence the sun hours in Wudil is averagely 8 hours (Oladosu & Adegbuluge, 1994).

2.2. Design Consideration for the Modified PV system

The system design tried to minimize the initial system costs by maximizing the system's energy efficiency. Efficient energy use lowers initial system cost. For example, reducing the electric lighting load by 75 percent, perhaps by shifting from incandescent to fluorescent lights, will reduce the number of modules and batteries needed for the system. Eliminating module shading by relocating the mounting system doesn't cost money and can increase the system's efficiency. Inefficiency caused by excessive voltage drop in the system's wiring can be reduced with proper wire sizing. In general, the design consider the some factors in order to optimize the PV system in the laboratory (Weis, 2013).

2.3. Sizing of PV System Components using Ampere Hour Load Method

Figure 1 illustrates the PV system, comprising components such as PV modules, charge controller, battery, inverter, and the load. Each component is meticulously sized to ensure optimal performance.

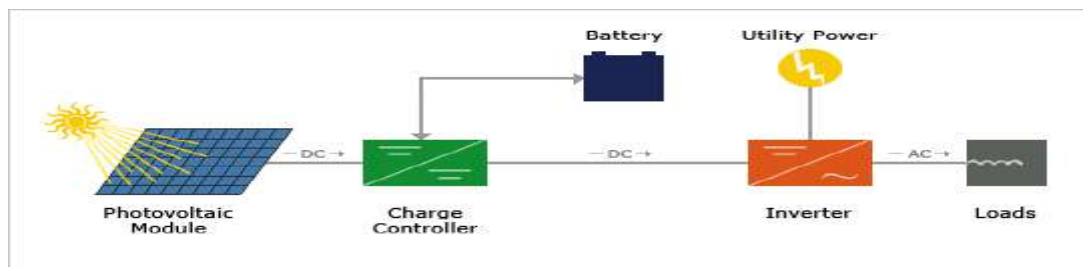


Figure 1. Schematic arrangement of the system

2.4. Electric Load Estimation

First of all, complete electric load was estimated by inputting the load, volts, amps, and usage information for each of the loads in a system. Upon completion total connected watts (AC and/or DC) and the average daily load (AC and/or DC) was determined. If the loads vary significantly on a seasonal or monthly basis or are of a critical nature, use the highest values in designing the system (Hankins, 2010).

$$A.D.L = \frac{PR \times \text{Daily Use} \times \text{Weekly Use}}{\text{Total weekly days}} \quad (1)$$

Where A.D.L is the Average Daily Load for each appliance, PR is the power rating of the appliances

$$\text{For Projector } A.D.L = \frac{320 \times 4 \times 5}{7} = 914.28 \text{ Wh}$$

$$\text{For Computers } A.D.L = \frac{130 \times 4 \times 5}{7} = 371.43 \text{ Wh}$$

$$\text{For Fans } A.D.L = \frac{160 \times 4 \times 5}{7} = 457.14 \text{ Wh}$$

$$\text{For Bulbs } A.D.L = \frac{60 \times 4 \times 5}{7} = 141.43 \text{ Wh}$$

$$A.D.L_{TOTAL} = \sum A.D.L \quad (2)$$

Where,

$A.D.L_{TOTAL}$ Is the appliances total Average Daily Load for the for AC load

$$\begin{aligned} A.D.L_{TOTAL} &= \sum A.D.L = (914.28 + 371.43 + 457.14 + 141.43) \\ &= 1884.28 Wh \end{aligned}$$

$$PR_{TOTAL} = \sum PR \quad (3)$$

$$PR_{TOTAL} = \sum PR = (320 + 130 + 160 + 60) = 670 \text{ Watt}$$

2.5. Battery Sizing

The average ampere hours per day of battery is determined using the equations below (Shankar et al., 2008):

$$A.A.H \text{ Per day} = \frac{A.D.L_{TOTAL}}{\text{Battery Nominal voltage}} \quad (4)$$

A.A.H per day is the average ampere hours per day of battery.

$$A.A.H \text{ Per day} = \frac{1884.28}{12} = 157.02 \text{ Ah/day}$$

Now that the average amp-hour per day load has been determined, the next step is designing an adequate battery bank.

The battery capacity required was determined using equation below;

$$\text{Battery Capacity} = \frac{A.A.H \text{ Per day} \times \text{Days of Autonomy}}{\text{Battery Discharge limit}} \quad (5)$$

Where discharge limit, or the battery's maximum depth of discharge is a number less than 1.0. Battery Discharge limit is 50% for lead acid battery and 80% for lithium ion battery, (Bala et al., 2019).

Days of Autonomy is 1 day

$$\text{Battery Capacity} = \frac{157.02 \times 1}{0.5} = 314.05 \text{ Ah}$$

The number of batteries in parallel is calculated using:

$$\text{No of parallel batteries} = \frac{\text{Battery Capacity}}{\text{Battery Ampere hour Capacity}} \quad (6)$$

$$\text{No of parallel batteries} = \frac{314.05}{100} = 3.14 \text{ Say 4 Battery}$$

The number of batteries in series is calculated using:

$$\text{No of Series battery} = \frac{\text{DC System Voltage}}{\text{Battery Norminal Voltage}} \quad (7)$$

$$\text{No of Series battery} = \frac{24}{12} = 2 \text{ Battery}$$

The total numbers of batteries required by the system were obtained using equation below;

$$\text{Total No of batteries} = \text{No. of parallel batteries} \times \text{No. of Series battery} \quad (8)$$

$$\text{Total No. of batteries} = 4 \times 2 = 8$$

2.6. Sizing of Solar Array

To begin sizing the array, you must increase the average daily load (amp-hour) to account for the inefficiency of the batteries and controller that have been selected (Hankins, 2010).

$$A.P.A = \frac{A.A.H \text{ Per day}}{\text{Battery efficiency}} \quad (9)$$

Where,

A.P.A is the Average Peak Ampere, Battery Efficiency is commonly considered as 0.8

$$A.P.A = \frac{157.02}{0.8} = 196.275 \text{ Ah/day}$$

The Average Peak Ampere of Array is calculated using:

$$A.P.A \text{ of array} = \frac{A.P.A}{\text{Peak Sun Hours per day}} \quad (10)$$

Peak sun hours *per day in kano is 8 hours*

$$A.P.A \text{ of array} = \frac{196.275}{8} = 24.53$$

$$\text{No of parallel module} = \frac{A.P.A \text{ of array}}{\text{Peak Ampere per module}} \quad (11)$$

Peak Ampere per module is 5.62 for 100Watt panels

$$\text{No of parallel module} = \frac{24.53}{5.62} = 4.36 \text{ Say } 5$$

$$\text{No. of Series module} = \frac{\text{DC System Voltage}}{\text{Module Nominal Voltage}} \quad (12)$$

DC System Voltage is 24V

$$\text{No. of Series module} = \frac{24}{12} = 2$$

$$\text{Total No. of module} = \text{No. of parallel module} \times \text{No of series module} \quad (13)$$

$$\text{Total No. of module} = 5 \times 2 = 10 \text{ modules}$$

2.7. Charge Controller Sizing

The charge controller sizing can be determined using equations below (Hankins, 2010);

$$ASC = MSP \times \text{No of parallel module} \quad (14)$$

Where ASC is the array short circuit and

MSC is the module short circuit and its 6.06A for 100W 12V panel

$$ASC = 6.06 \times 10 = 60.6A$$

The design controller capacity was obtained using equation

$$\begin{aligned} \text{Controller capacity} &= (1 + 25\%) \times ASC = 1.25ASC \\ \text{Controller capacity} &= 1.25 \times 60.6 = 75.75 \text{ A Say } 80 \text{ A} \end{aligned} \quad (15)$$

3. Inverter Sizing

In general, inverter should be over sized by 25% of the load to increase reliability and life time.

Inverter rating was obtained using equations below (Hankins, 2010).

$$\text{Total energy demanded} = \frac{PR_{TOTAL}}{0.8} \tag{16}$$

$$\text{Total energy demanded} = \frac{PR_{TOTAL}}{0.8} = \frac{670}{0.8} = 837.5 \text{ Watt}$$

$$\text{Inverter rating} = 1.25 \times \text{Total energy demanded} \tag{17}$$

$$\text{Inverter rating} = 1.25 \times 837.5 = 1046.875 \text{ W Say } 1500 \text{ W}$$

Table 2. Summary of quantity of the components needed.

Component	Designed parameters	Quantity	Selected component
Battery	314.05 Ah capacity 4pieces parallel connection 2pieces series connection	8	100 Ah, 12V
Array/ Panels	24.53A Av. Peak Ampere of array 5 parallel connection module 2 series connection module	10	100W 12V
Controller	75.75A Controller capacity	1	80A
Inverter	1046.875W Rating	1	1.5KW 12V

4. RESULT AND DISCUSSION

The results obtained in this work are presented, and the discussion of these results is well explained in this section.

4.1. Result Analysis

The monthly average load demand over a year was quantified and tabulated as shown in Table 3, alongside the average power output recorded by the existing PV system throughout the entirety of 2021, as monitored by the intelligent charge controller. Furthermore, the average power output of the modified PV system per month was assessed for the entire duration of 2022. Notably, it's pertinent to mention that the prevailing environmental conditions governing sunlight in Kano State remained relatively consistent over this period. All pertinent data points are summarized within Table 3 for comprehensive analysis.

Table 3: power generated by old and modified PV over the year 2021 and 2022

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Average Power generated by old PV system monthly (Watt)	1950	2000	2050	2060	2060	2200	2200	2000	2000	1900	1800	1750
Average Power generated by modified system PV monthly (Watt)	4000	4150	4200	4200	4220	4220	4220	4200	4200	4100	3900	3850

Load requirement (Watt)	3900	4020	4040	4050	4050	4100	4100	4030	4010	4000	3800	3800
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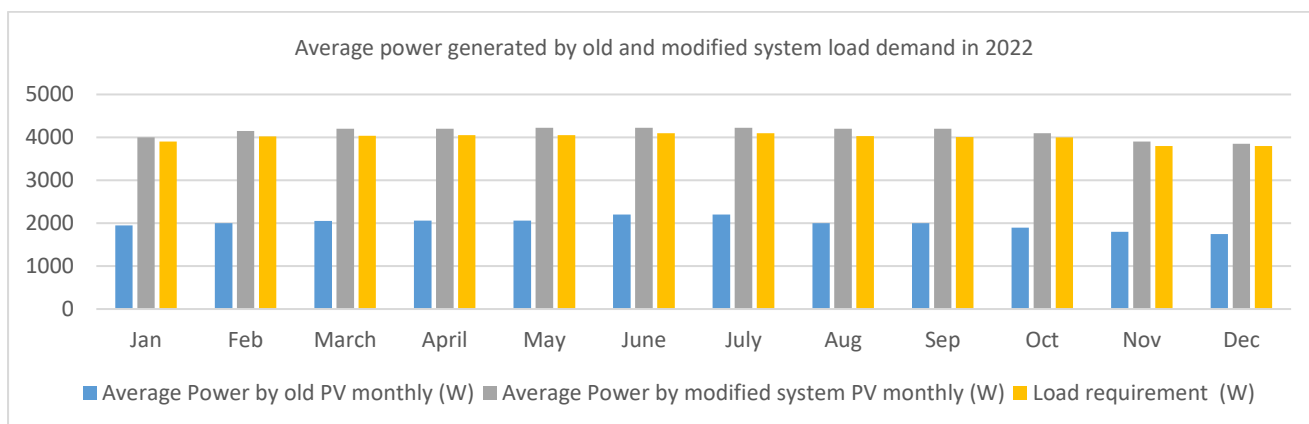


Figure 2: Power generated from old and modified PV system with respect to load demand

4.2. Result Discussion

The sizing of PV system components using the Ampere Hour Load Method involved meticulous calculations to ensure optimal performance. Electric load estimation yielded a total Average Daily Load (A.D.L) of 1884.28 Wh, with a cumulative power rating (PR_TOTAL) of 670 Watts. Battery sizing calculations determined a required capacity of 314.05 Ah, necessitating the installation of 8 batteries in total, arranged in 4 parallel connections and 2 series connections. The solar array was sized to deliver an Average Peak Ampere (A.P.A) of 196.275 Ah/day, leading to the configuration of 5 parallel modules and 2 series modules, totalling 10 modules. Charge controller sizing resulted in a designed capacity of 80 A, ensuring efficient regulation of the solar array output. The inverter was sized at 1500 W, 25% larger than the total energy demanded of 837.5 Watts, to enhance reliability and accommodate potential load variations.

The current PV system in the AutoCAD Lab at KUST Wudil is insufficient for effective power supply, causing disruptions in learning, teaching, and research. Despite efforts, it fails to sustain essential equipment operation simultaneously, resulting in frequent disruptions. Load requirement ranges from 3800 to 4050 Watts monthly, while the old PV system generates only 1750 to 2200 Watts per month, consistently falling short. A comprehensive redesign and installation of a modified PV system were undertaken to address this issue. The modified system's performance from January to December 2022 shows significant improvement, consistently exceeding load requirements with monthly average power ranging from 3850 to 4220 Watts. This ensures uninterrupted operation of equipment, enhancing learning, teaching, and research activities. The success of the modified system underscores the importance of appropriately sizing and designing renewable energy systems for educational and research facilities, especially in energy-shortage-prone regions.

5. CONCLUSION

In conclusion, this study has effectively addressed the deficiencies of the existing photovoltaic (PV) system in the AutoCAD Lab, where insufficient power hindered the operation of essential equipment. Through comprehensive redesign, sizing, and installation efforts, the modified PV system has demonstrated significant improvements. For example, the average monthly power generation increased from 1950 to 2200 Watts in 2021 with the old system to a range of 3850 to 4220 Watts in 2022 with the modified system, consistently surpassing the load requirements, which varied from 3800 to 4050 Watts. This enhancement has ensured uninterrupted operation, facilitating improved learning environments and research activities. The success of this endeavour underscores the necessity of tailored renewable energy system design. Moving forward, ongoing monitoring will be vital for ensuring optimal performance and meeting evolving energy demands. Future directions could include further optimization of the PV system, exploration of additional renewable energy sources, and integration of smart energy management technologies to enhance efficiency and sustainability.

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