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RESEARCH ARTICLE - MATHEMATICS

Design and Implementation of Hybrid Solar PV system

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Abstract

A hybrid solar photovoltaic system can supply homes and all government and private sector buildings with electricity in cities and remote places. Solar PV systems generate emission-free electricity that is stable, safe, noise-free, easy to use and does not require refuelling. It also reduces the use of fossil fuels in power plants and reduces pollutants and greenhouse gas emissions that cause climate damage, Therefore, the current research aims to design and implement a hybrid photovoltaic solar system to provide one of the laboratories of the Department of Physics at the college of education, Mustansiriya University, with electrical energy during a year. The total electrical energy consumed by the loads in the laboratory (devices, lighting lamps and fans) was measured by about 2000 watts. The working hours of the laboratory were estimated at six hours. In light of that, a photovoltaic solar system consisting of eight solar panels with a capacity of 545 watts per panel was designed in standard conditions and a total capacity of 4360 watts. After the design and installation, the laboratory was operated at its total capacity and the power supplied by the panels to the laboratory was recorded during the first daylight until after midday. The results were encouraging, as it was found that the net power processed by the system is about 3500 watts. Therefore, we can conclude that the construction of solar systems is an economically feasible process under the conditions of severe shortage in the supply of electrical energy and the high cost of purchasing electrical energy from the private sector.

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Key Words: solar radiation, solar cells, solar modules, on-grid solar PV systems, hybrid solar PV systems.

1. Introduction

Energy is an important element in development in all areas of life and an important element in human development. With the increasing human growth and rapid technological development, the energy demand has increased. The Middle East's abundant and cheap energy sources of fossil fuels have contributed significantly to these developments [1].

Despite the importance of fossil fuels as one of the greatest sources of energy that are used in all joints of life, their quantity is determined to disappear. Its use is also accompanied by the emission of pollutants and greenhouse gases, which are the main cause of the greenhouse effect. Therefore, the world began to search for alternative energy sources and found that the sun is one of the greatest of these sources. The sun is a source of clean, environmentally friendly and inexhaustible energy. The energy required to keep life in our solar system going comes from the sun. The sun provides the Earth with enough energy in an hour to cover its energy needs for around a year[2]. Putting money into solar energy in Iraq helps to provide electricity, particularly given the country's current electrical energy shortage. It also helps to lessen the environmental pollution caused by conventional factories and power plants [3, 4]. Solar energy can be used by converting it directly into electrical energy using photovoltaic solar panels. Photovoltaic solar panels are the main component of solar energy systems that are widely used around the world in the production of electrical energy. There are three types of solar systems used to produce electrical energy by taking advantage of solar radiation. These types are the on-grid (grid-tide), off-grid (standalone), and the hybrid. The grid-tied solar system consists of a set of solar PV panels, an inverter and power meters. The inverter converts the continuous electrical power supplied by the solar panels into alternating electrical power. In the event of an excess of electrical power for the need of the house or the place of consumption, the inverter supplies the national electricity grid with this surplus power. If the sun is absent due to clouds or during the night, this type of system does not work because it does not contain batteries [5].

In remote places without a national grid, the off-grid photovoltaic solar system is used to supply electrical energy to homes. This system consists of a set of photovoltaic solar panels, an inverter and a bank of batteries. The DC generated by the solar panels is converted into alternating current that feeds home devices and if there is any excess amount of electricity, it is stored in batteries that act as an energy source in the absence of solar energy. Sometimes a diesel generator is installed with this system if there is a lack of supply of electrical power from the system [6]. In hybrid solar systems, the two grid-connected and off-grid solar PV systems are combined. They are suitable for use as they contribute directly to reducing the cost of electricity. In these systems, the wide spectrum of solar radiation is converted into electrical energy that feeds electrical loads in homes or places of consumption during the day, and excess of it is stored in batteries as in the off-grid system. If the batteries are fully charged, this type of system supplies the national grid with excess electrical energy, as is the case with on-grid photovoltaic solar systems[7], [8] see Fig. 1.

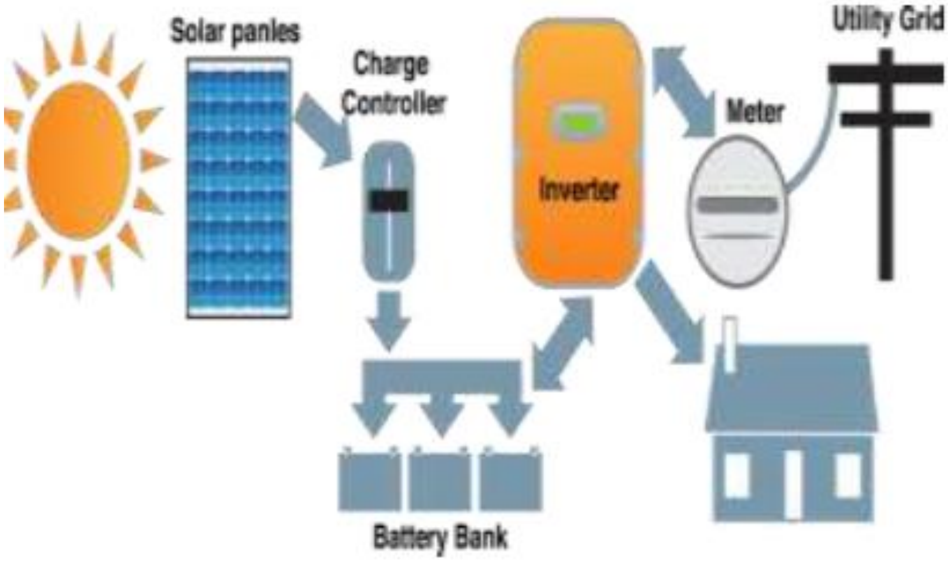

Figure 1. Hybrid solar PV system [6].

The Iraqi atmosphere is rich in solar energy, as Iraq occupies an advanced position on the list of countries rich in solar activity, and many local studies have confirmed the suitability of the Iraqi environment for investing solar energy in the production of electricity[9], [10]. Therefore, the current study aims to design and implement a hybrid photovoltaic solar system to equip the electronic laboratory of the Department of Physics at the College of Education at Mustansiriya University with electrical energy. This experiment is the first of its kind at the level of the university education sector and a step towards the adoption of solar energy in the operation of all institutions of higher education and scientific research.

Abdulrahman S. Al-Buraiki   et al[11]. To size off-grid PV/battery renewable systems to meet different load requirements, like street lighting, industrial and residential applications, load balancing, and irrigation, they carried out technical and economic optimization. This study aimed to investigate how load coordination with solar potential affects the ideal size and cost of a photovoltaic system. It is necessary to determine how many hours the sun shines at the target location (Dammam, Saudi Arabia) in order to achieve this.

Pablo B. M, et al[12] By examining how tariff incentives affect the optimal performance of grid-connected battery-powered PV systems, this study contributes to our understanding of the acceptance and adoption of battery-powered PV systems in Poland. The results show that installing a PV system reduces residential household energy expenditure by 40%, from €475.53 to €287.18.T.

Adefarati et al [13] Their objective is to ascertain whether using a hybrid energy system (HES) to power a remote community is feasible from an environmental, economical, and technological standpoint. In order to meet the electrical power needs of an agricultural settlement in Kura, Nigeria, this study provides the optimal design of a standalone HES system with a diesel generator (DG), photovoltaic (PV), and battery storage system (BSS), while taking generational constraints and load demand into consideration. Joseph J. Akpan et al[14] commenced developing a system capable of providing Wukari with enough energy to run a standard home. The main structural elements are covered, including the inverter, charge controller, battery, and PV panels. Together with the insulation level and the ten (10) hours of daily average sunshine exposure, the estimated total cost of the system is also taken into account. The building will require 5190 W of electricity in total to power its load devices from the PV source. These devices were powered by four 24V-200Ah batteries in the battery bank, which had a system battery capacity of 848Ah; one 50A-24V charge controller; four 220W modules at 1000W/m2 and 25°C standard test conditions (STC); and a 2kVA inverter. The goal of this work was to design a suitable off-grid PV system or stand-alone that can produce a dependable power supply for the residential area around the clock, removing reliance on the home grid, and determining the appropriate size of each PV system component based on the quantity, kind, and electrical capacity of the devices.

2. Design considerations of hybrid solar PV system

The hybrid solar PV system is designed to provide the daily electricity demand required to operate a specified number of loads. This solar PV system consisting of a set of solar modules can secure charging for a specific set of batteries so that the devices continue to operate. Sufficient storage capacity for electric power must be ensured to ensure that devices operate at night and at times when sunlight is dim due to clouds and for a certain number of days by securing enough batteries. The sizes and integration of solar system components must be taken into account in design to ensure reliable operation.

Designing a hybrid solar PV system for an electronic laboratory involves calculating daily energy demand. The Power consumption per load is measured in watts, and its operation time is calculated in hours. Load and run times vary according to the type of device. To calculate the size of a hybrid PV system, carefully record the load and time of use of each device[15]. To calculate an individual load's energy demand in W-h (watt-hours), multiply the power consumption of any device by the duration of use[16].

$$E_i = P_i T_u \tag{1}$$

While P_i indicates a load's rating in watts, T_u indicates the load's period of use each day in hours, and E_i indicates the energy consumption of a single load in watt-hours per day. The daily energy demand in W-h for all devices can be computed using the following mathematical expression:

$$E_t = \sum E_i = \sum (P_i T_u) \tag{2}$$

The output electricity of PV panels or modules varies based on size and market availability. Peak-wattage ratings are determined by the chosen location's module size and weather conditions[17]. To calculate the size and number of PV modules needed for specific loads, the rated peak watts of the chosen panel must be known. Use the formula to compute the overall size of solar panels or PV arrays against specific load demand[17], [18].

$$P_{t-PV} = \frac{E_t}{PGF} x1.3 \tag{3}$$

Where $P_{t\text{-}PV}$ is the total size of the PV array in watts, PGF is the power generation factor (1.3). The power generation factor in Equation 3 considers climate conditions at various site locations[17]. The most frequent mathematical relationship for calculating the overall size of a PV array is to utilise the mean daily insolation in peak-sun hours to operate the required load[15], [19].

$$P_{t-PV} = \frac{Et}{T_{peak-hours}} x1.25 \tag{4}$$

Where $T_{peak\text{-}hours}$ is the lowest daily average peak-sun hours (solar fuel) of a month in a year, the value 1.25 represents the scaling factor same as in equation 3. Therefore, the number of PV modules or panels required against the total size of the PV array in equation 3 or 4 is computed using the peak watts of the chosen panel size on the market availability as:

$$N_{modules} = \frac{P_{t-PV}}{W_{pi}} \quad (5)$$

Where $N_{modules}$ is the total number of modules and W_{pi} is the selected module's peak-watts rating in watts. A solar charge controller's size is determined by its voltage and current ratings. Using the short-circuit rated current of certain PV modules, the rated current value is computed. However, the nominal voltage of a battery and the rated voltage have the same value. Accordingly, the rated current or ampere size of the solar charge controller can be computed analytically as follows [16], [17]:

$$I_{scc} = I_{sc} x 1.3 \quad (6)$$

Where I_{scc} is the size of the solar charge controller in amperage, I_{sc} is the short circuit (rated current) of the selected PV unit, and the value 1.3 is the safety factor.

The size of batteries is expressed in ampere-hour (Ah). Many aspects are considered while choosing and sizing batteries. These variables include the battery's nominal voltage, cloudy days, inverter size and efficiency, depth of discharge, and the device's overall load[15]. Typically, there are three cloudy days (days of autonomy)[20]. Consequently, it is recommended to increase the battery size by 1.5–3 times[21] . Battery size for a given load demand can be computed using the following formula[16]:

$$(Ah)_{bank} = \frac{E_t}{V_{dc-sys}} \frac{D_{aut}}{DOD} \quad (7)$$

Where $(Ah)_{bank}$ is the size or capacity of the battery bank in ampere-hours, V_{dc-sys} is the solar system voltage in DC, D_{aut} is the days of autonomy and DOD is the depth of discharge of the battery. Thus, the number of batteries required to construct the size of the battery bank in equation 7 is calculated as follows using the size of a single battery as market availability.

$$N_{batteries} = \frac{(Ah)_{bank}}{(Ah)_{battery}} \quad (8)$$

Where $N_{batteries}$ is the total number of batteries needed about the size of the $(Ah)_{bank}$ is known as the (Ah) battery's capacity, measured in ampere-hours. An inverter is often selected based on several factors, such as cost, upkeep needs, dependability, frequency and voltage management, and efficiency [22]. The PV array output, which takes the overall load into account, is used to optimize the inverter's size. The voltage of the inverter and battery bank should not be out of sync. In a hybrid system, the inverter's output capacity needs to be large enough to sustain the power demand during peak load. To guarantee safety, its size should therefore be 20–30% greater than the total power of all the loads[20], [21]. Furthermore, the size of the inverter should be 3-5 times larger than the power needed by the device if it requires a motor or compressor to operate [23]. Therefore, the following formula is used to determine the inverter's size:[24]

$$(VA)_{inv} = (VA)_{t-load} \times CF \quad (9)$$

The total electrical load $(VA)_{t-load}$ is determined by adding the (VA)inv of all the individual loads, where (VA)inv is the inverter's rating in volt-ampere, CF is the correction factor for safety, and its value is 3 for motor loads and 1.25 for simple loads without motors.

$$(VA)_{t-load} = \sum (VA)i = \sum \frac{P_i}{P_f} \quad (10)$$

Where P_f is the power factor of each load.

3. A case study

This work took place at Mustansiriyah University, specifically in the building of the College of Education, where the PV solar system supplies the electronic laboratory of the physics department with electrical energy. This system consists of eight solar panels connected in series with a power of 4.36 kW (see Fig. 2). Table 1 represents the specifications of a monocrystalline solar module kind of JinKO (JKM545M-72HL4-V JK03M) solar panel (under standard conditions, air mass 1.5, irradiance 1000 W/m^2, and cell temperature 25 ^oC).

Figure 2. PV system on the roof of the College of Education, Mustansiriyah University,Baghdad, Iraq.

Table 1: Specifications and Mechanical Characteristics of the Solar Module (JKM545M-72HL4-V JK03M) at (STC).

Parameter	Value
Maximum power P_{max} (W)	545.0
Maximum power Voltage V_{mp} (V)	40.80
Maximum Power Current I_{mp} (A)	13.36
Open-Circuit Voltage V_{oc} (V)	49.52
Short-Circuit Current I_{sc} (A)	13.94
Fill Factor	78.95%
Module efficiency	21.13%
Temperature coefficients of P_{max}	-0.35%/℃
Temperature coefficients of V_{oc}	-0.28%/℃
Temperature coefficients of I_{sc}	0.048%/℃
Nominal operating cell temperature (NOCT)	45±2℃
Cell Type	P- P-type mono-crystalline
Number of cells	144 (6×24)
Dimensions	2274×1134×35 mm (89.53×44.65×1.38 inch)
Weight	28.9 kg (63.7 lbs)

4. Results and Discussion

Due to the Baghdad weather and the PV solar system's location, built to provide the physics electronic laboratory with electricity, monthly solar radiation rates were utilized to extract the peak sun hours, which were used in subsequent calculations. For every month of 2023, the average solar radiation falling on the horizontal surface was computed in Wh/m^2/day (see Fig. 3). Incident solar radiation levels rose as summer approached and peaked in July at roughly 8.2 kWh/m^2/day. Fig.4 illustrates how variations in the amount of incident solar radiation throughout the year led to variations in the peak sun hours, representing the solar fuel. In July, the number of peak solar hours reaches approximately 8.2 hours. Additionally, there are roughly 5.65 hours of peak sun exposure each year.

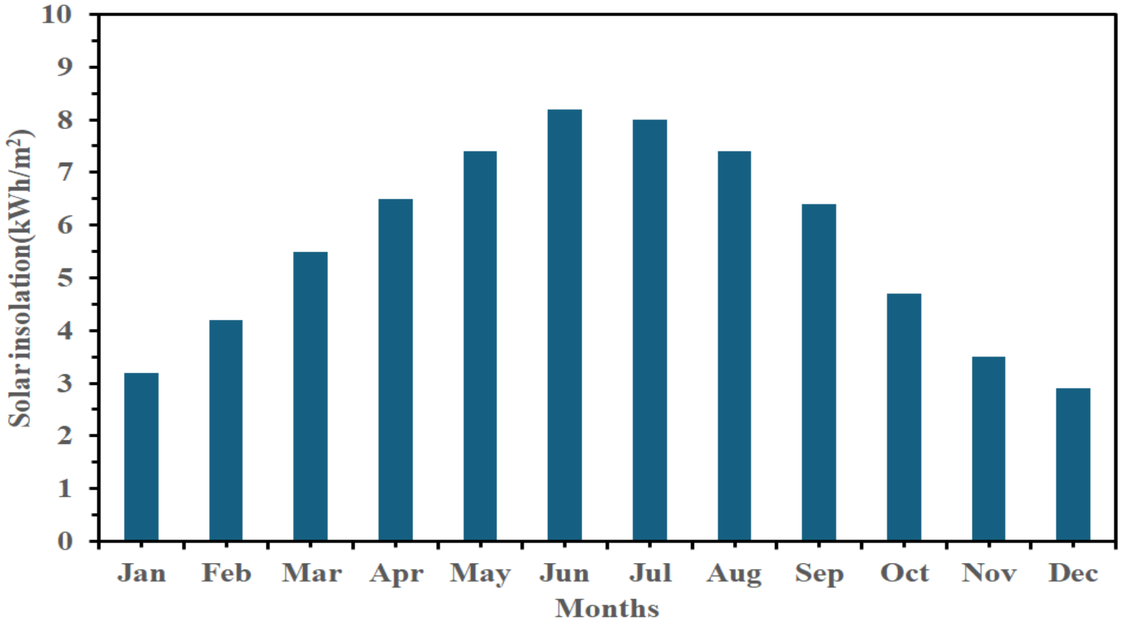

Figure 3. Variation of monthly-daily global solar radiation during a year

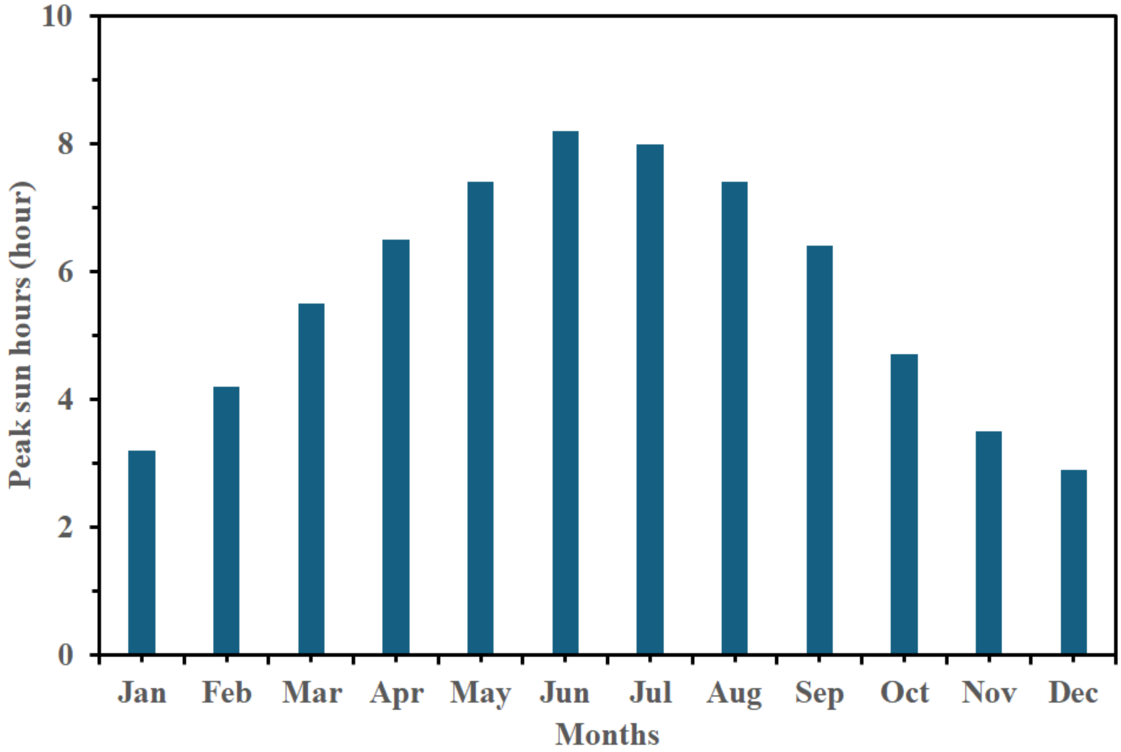

Figure 4. Variation of the average of peak sun hours per month during a year.

The system was designed based on the average value of the number of hours of solar insolation that occurs in the year (5.65 hours). So, the total energy demand per day of all the loads depends on the rating of individual loads and the time of use of that load per day (supplying hours). For the physics electronic laboratory, the total energy demand was increased as the supply hours increased as shown in Fig.5.

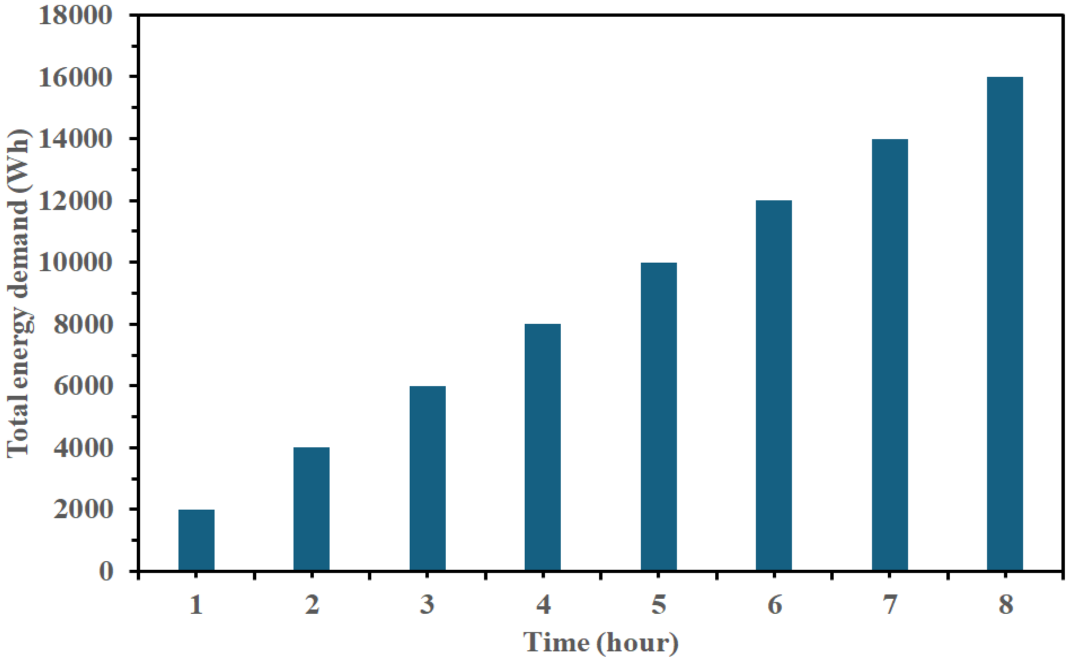

Figure 5: Variation of total energy demand per day as a function of supplying hours (active energy of the load is ~2000W).

The design of the size of solar modules to prepare a specific load depends on two main factors: the number of supplying hours and the value of solar fuel (peak sun hours, 5.65 hours in Baghdad). In the case of designing the solar photovoltaic system according to the annual rate of solar fuel, the change in the size of the solar modules with the number of supplying hours is shown in Fig. 6. For each case of supplying hours, the total size of solar modules against specific load demand takes different values and these values will be changed over the year due to changes in daily peak sun hours. Accordingly, the total size of solar modules against specific load demand (~2000W) reaches its minimum values in the summer season where the peak sun hours are high as shown in Fig.7. In most cases, the average time during which the laboratory works is six hours a day and according to this time, a photovoltaic solar system is designed to supply the electron laboratory with electrical energy throughout the months of the year

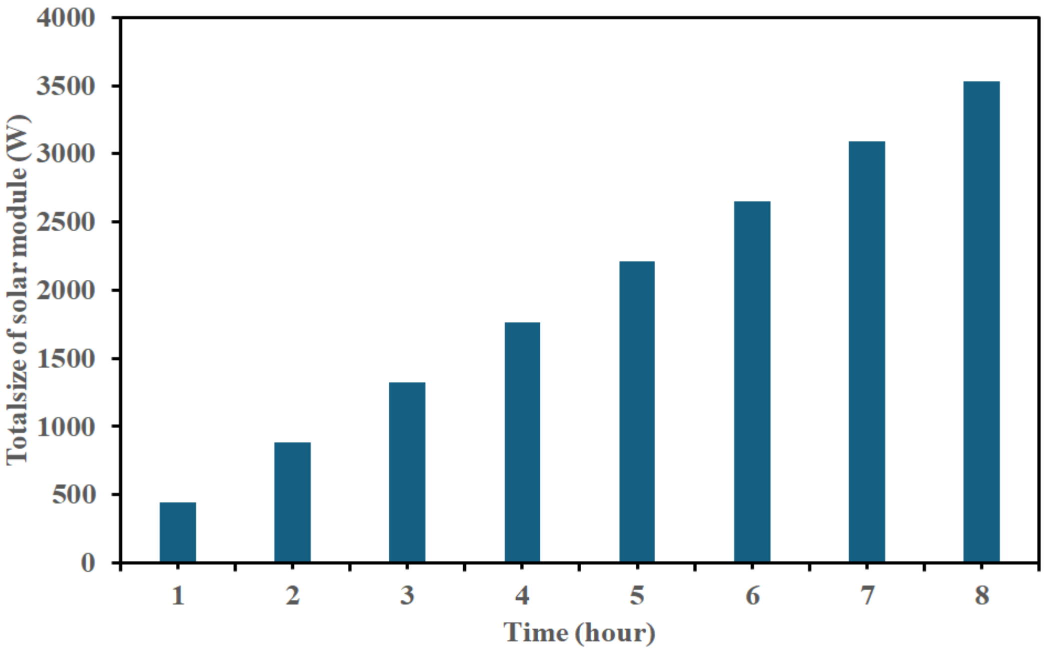

Figure 6: Variation of the total size of the solar modules as a function of supplying hours (active energy of the load is ~2000W).

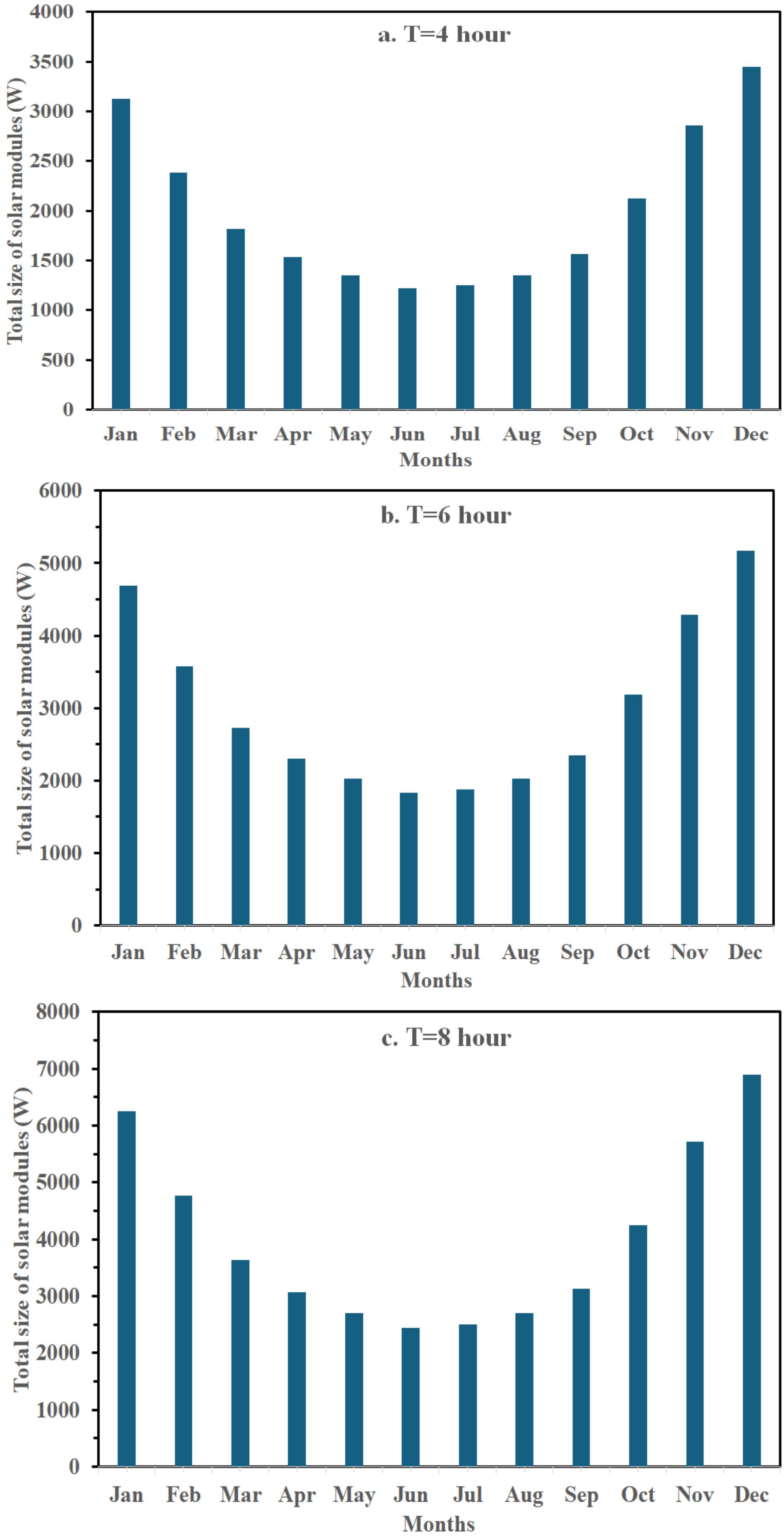

Figure 7(a, b, c). Variation of the total size of solar modules during a year for different supplying times.

The number of solar modules required to cover the above sizes of solar modules depends on the specification of the solar modules used. For mono-crystalline solar PV modules (see Table 2), the number of required solar modules differs according to time in year and supplying hours (6 hours) as shown in Fig. 8. According to this Figure, about eight panels are enough to supply the laboratory with electrical energy for most of the year.

For the specific value of solar system voltage (in the present work Vdc-sy= 48 V), the size of the battery bank depends on the total demand energy per day of the load and the days of autonomy. For specific days of autonomy (1 day) Fig.9 shows a suitable number of batteries to feed the load (2000 W) with electrical energy in the absence of the sun and absence of national electricity during a year. This number is calculated when the size of the individual battery is 100 A/hr.

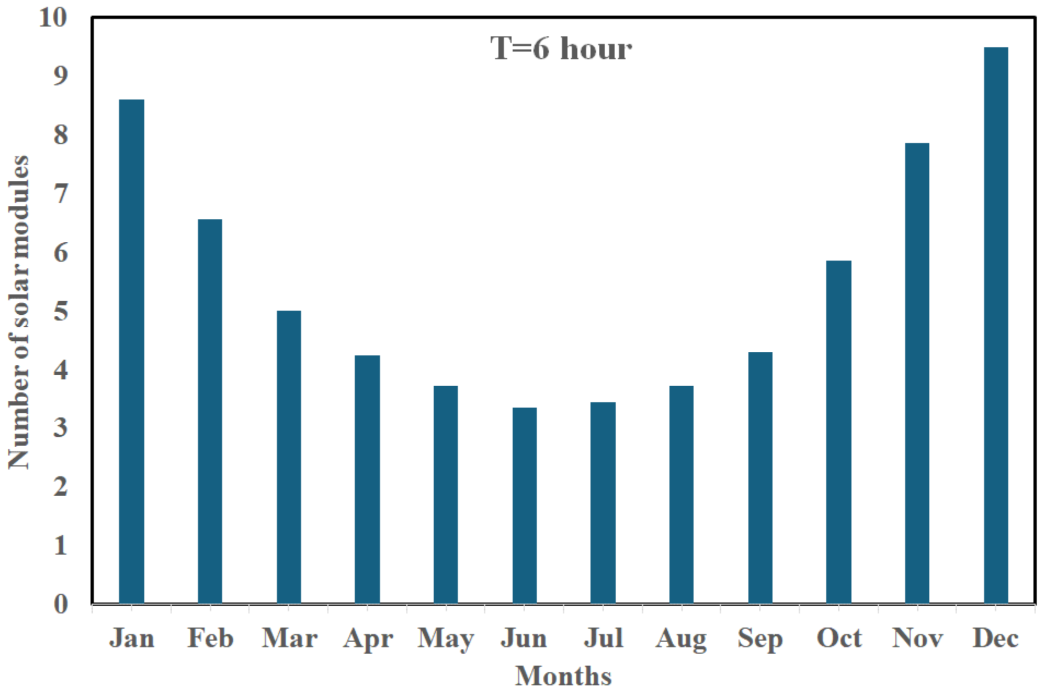

Figure 8. Variation of several solar modules as a function of time during a year.

The charge regulator is a device that regulates the entry of electrical charges sent from solar panels to the batteries or battery, and when the battery takes the electrical charge necessary for it (or in other words when the battery is full), the device separates the energy that is sent to the battery so that the battery is not damaged by electrical energy. The charging regulator current was used in the current work 18 A.

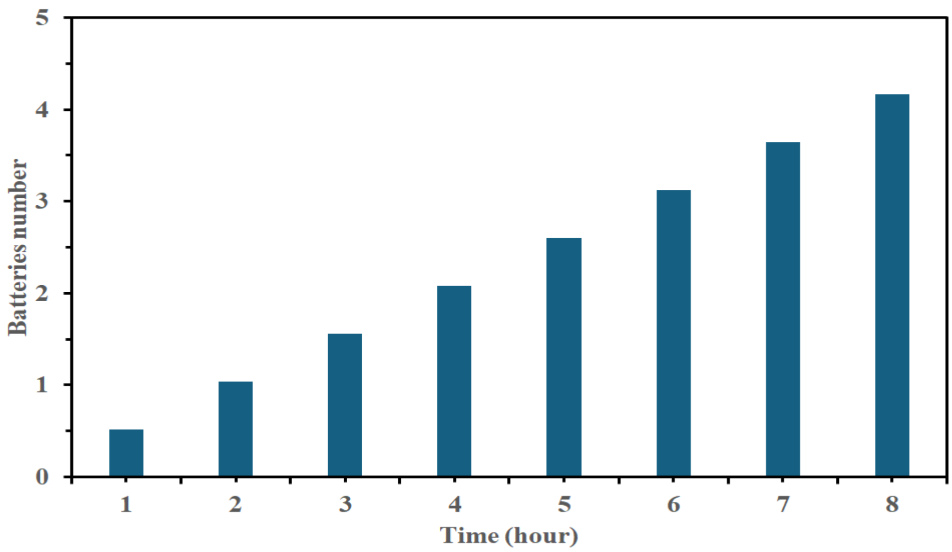

Figure 9. Number of batteries according to supplying time

The choice of inverter depends mainly on the size of the solar system and its efficiency is taken into account. A hybrid inverter combining the functions of a grid-connected and off-grid inverter was selected with a capacity of 4.5 kAV to be compatible with the present solar system.

5. Testing of energy demand in electron laboratory

On July 29, 2024, some of the electronic laboratory equipment, such as light bulbs and fans, was turned on to determine the amount of electrical energy consumed in the electron laboratory. According to the data, the system supplies the energy of 1.81 kW, while the energy consumed in the laboratory when operating lamps and ceiling fans is 1.46 kW as shown in Fig. 10 and Table 2.

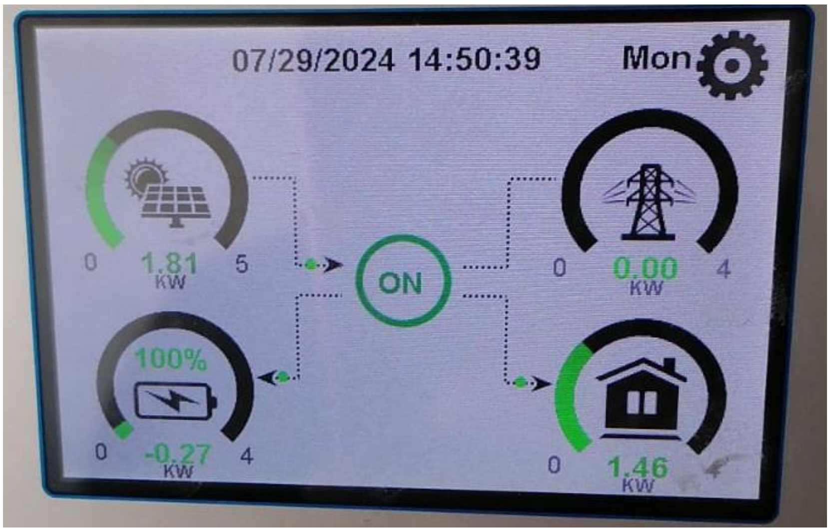

Figure 10. Inverter device.

Table 2: Energy demand in an electron laboratory.

Device name	Number of devices	Device power (Watt)	Supplying hours (hour)	Energy demand (Watt-hour)
Fans	5	500	6	3000
Light bulbs	8	960	6	5760
Other devices	8	540	6	3240
annual		2000		12000

Figure 11: Electronics laboratory.

6. Conclusions

This paper recommends the appropriate size of PV modules, solar charge controllers, battery banks, and DC/AC inverters based on load and daily use. In light of the current conditions in Iraq, which are suffering from a severe shortage in the supply of electrical energy, it has become necessary to design and implement solar photovoltaic systems on the roofs of citizens' homes. As one of the most important conclusions that have been known from the current research is the possibility and ease of citizens to invest in solar energy because Iraq is rich in this type of energy and the low prices of these systems in light of the tremendous development in the field of solar panels and solar batteries industry and the competition of international companies in this field. The installation of these systems reduces the burden on the national grid and reduces the rates of environmental pollution and reduces the expenses of purchasing electrical energy except from the government sector or special sector.

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Reference

[1] J. Goldemberg, “World energy assessment. Energy and the challenge of sustainability,” 2001.
[2] R. A. Messenger and A. Abtahi, Photovoltaic systems engineering. CRC press, 2018.
[3] Y. Mohammed Kalf and A. F. Atwan, “Performance Analysis of 15kW Solar PV System,” Mustansiriyah J. Pure Appl. Sci., vol. 1325, no. 1, pp. 1–14, 2024, doi: 10.1088/1755-1315/1325/1/012034.
[4] Nidal S. Mohammed , Ahmed F. Atwan , Naseer K. Kasim, "Enhancement of Geothermal Energy in Rationalization of Electrical Power Consumption", MJPAS Vol. 1, No. 1 (2023) 20 – 29.
[5] N. M. Kumar, M. S. P. Subathra, and J. E. Moses, “On-grid solar photovoltaic system: components, design considerations, and case study,” in 2018 4th International Conference on Electrical Energy Systems (ICEES), IEEE, 2018, pp. 616–619.
[6] T. Maddileti and L. Cherukuri, “Review on types of solar power systems,” J. Eng. Sci., 2019.
[7] J. Koko, A. Riza, and U. K. M. Khadik, “Design of solar power plants with hybrid systems,” in IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, p. 12074.
[8] M. Alktranee and P. Bencs, “Overview of the hybrid solar system,” Analecta Tech. Szeged., vol. 14, no. 1, pp. 100–108, 2020.
[9] N. K. Kasim, F. S. Z. Alabdeen, J. S. Hameed, and A. F. Atwan, “Evaluation and improvement the performance of MCM solar modules in Iraqi environments,” in AIP Conference Proceedings, AIP Publishing, 2019.
[10] Y. M. Kalf and A. F. Atwan, “Performance Analysis of 25kW p-Si Solar PV System,” in IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2024, p. 12034.
[11] A. S. Al-Buraiki, A. Al-Sharafi, B. S. Yilbas, A. S. Al-Merbati, and M. Kassas, “Influence of load coordination with solar energy potential on the optimal sizing of standalone PV systems,” Energy Convers. Manag. X, vol. 17, p. 100343, 2023.
[12] P. Benalcazar, M. Kalka, and J. Kamiński, “From consumer to prosumer: A model-based analysis of costs and benefits of grid-connected residential PV-battery systems,” Energy Policy, vol. 191, p. 114167, 2024.
[13] T. Adefarati et al., “Design and techno-economic assessment of a standalone photovoltaic-diesel-battery hybrid energy system for electrification of rural areas: A step towards sustainable development,” Renew. Energy, vol. 227, p. 120556, 2024.
[14] J. J. Akpan, P. O. Udom, and J. F. Wansah, “Typical Off grid/Stand-Alone Photovoltaic System Design for Household Power Generation in Wukari Metropolis,” J. Res. Eng. Comput. Sci., vol. 2, no. 2, pp. 34–47, 2024.
[15] W. Ali, H. Farooq, M. Usama, M. Ahmed, M. Ali, and A. Khushboo, “Design and implementation of solar energy based water chilling system,” J. Fac. Eng. Technol., vol. 25, no. 1, pp. xx–xx, 2018.
[16] E. N. A. AlShemmary, L. M. Kadhom, and W. J. Al-Fahham, “Information technology and

stand-alone solar systems in tertiary institutions,” Energy Procedia, vol. 36, pp. 369–379, 2013.

[17] W. Ali, H. Farooq, A. U. Rehman, Q. Awais, M. Jamil, and A. Noman, “Design considerations of stand-alone solar photovoltaic systems,” in 2018 International conference on computing, electronic and electrical engineering (ICE Cube), IEEE, 2018, pp. 1–6.

[18] Nidal Salih Mohammed, Naseer K. Kasim , Ahmed F. Atwan, "Stand-Alone Solar PV-System for powering the Compression AirConditioning Systems in Iraqi Environment", Journal of collage of Education, No. 2, Issue 2, 2022.

[19] J. Parmar, “Calculate Size of Solar Panel,” 2016, Jan.

[20] S. Jadhav, S. Patil, D. Yadav, and N. Kulkarni, “Design Considerations of Stand-Alone Solar Photovoltaic System”.

[21] T. H. Ghoto, M. A. Wassan, A. A. Nohani, and A. Junejo, “Performance evaluation and model development of solar photovoltaic system: a case study for Hyderabad,” in 4th Int. Conf. Energy, Environment and Sustainable Development, 2016, pp. 1–7.

[22] P. Mohanty and M. Gujar, “PV component selection for off-grid applications,” in Solar Photovoltaic System Applications: A Guidebook for Off-Grid Electrification, Springer, 2015, pp. 85–106.

[23] D. Lauria and M. Coppola, “Design and control of an advanced PV inverter,” Sol. Energy, vol. 110, pp. 533–542, 2014.

[24] P. A. Lynn, Electricity from sunlight: an introduction to photovoltaics. John Wiley & Sons, 2011.