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Design and Simulation of a PV Solar System with Silicon Hetero-Junction Technology (HJT) for a Residential Stand-Alone "off Grid" System with Batteries Using PV Syst Software in Iraq/Baghdad

Ahmad Al-Sarraj[1*], Marwah Sabah Mehdi[2], Omar S. Mahdi[3]

[1,2]Ministry of Higher Education and Scientific Research, Iraq-Baghdad*
[3]Chemical Engineering, Faculty of Engineering - University of Technology, Iraq-Baghdad

Email: [2]marwasabah8941@gmail.com, [3]omar.s.mahdy@uotechnology.edu.iq
Corresponding Email: [1]ahmed.emad846@gmail.com*

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***Abstract:** Recently, the environment has been negatively impacted by the excessive CO_2 emissions caused by the wide usage of fossil fuels in electricity generation. If this continued, it is predicted that the temperature of the atmosphere would rise, causing an increase in storms, hurricanes, droughts, dust, and floods. Therefore, as renewable energy produces little to no emissions, there is an urgent need to adapt it in recent times. Meanwhile, The PV sector has experienced rapid growth in recent years. The PV sector is embracing new technology, and the cell efficiency has been rising rapidly like Silicon Hetero- junction technology HJT which has offered additional benefits: It offers a well-suited application to reach efficiencies above 23% with process temperatures below 200°C. HJT solar panels have >90% module bifaciality and a low temperature coefficient (-0.3 %/C°), and provide additional benefit to the Levelized Cost of Energy LCOE and output power for PV systems.*

This study intends to assess the efficiency of a residential off-grid system with (HJT) PV panels at a total power of 2.0 kWh and the daily power close to 10 KWh/day with a 48V system in Iraq/Baghdad. PVsyst (7.2.11 version) software has been used for the analysis to calculate the energy output, and enhancing the system design. The characteristics, solar radiation, and ambient temperature are also included in the meteorological data used for evaluation, which is taken from PVsyst's database.

***Keywords:** Photovoltaic, Solar Cells, Silicon Hetero-Junctions, Pvsyst.*

1. INTRODUCTION

PV (photovoltaic) system development is expanding. They play a crucial role in the globe as a renewable energy source by creating a safe environment. The photovoltaic (PV) system must be built to operate at its highest efficiency in order to maintain the maximum power of the solar panel while the weather is suitable [1].

The climatic conditions of a specific location have a significant impact on the PV system's efficiency. In addition, The installation material method of the photovoltaic cell, the system's inclination or orientation, the positioning of the PV cells in the system, the local climate, and other factors all have an impact on a PV system's overall efficiency. Therefore, it is essential to study and examine these elements in order to learn more about the characteristics that influence in a PV system's ability to generate power. Although, analysis can be done manually, technology has made it possible to create a variety of simulation software, including PVsyst, PV Planner, Homer Pro, etc. PVsyst has been used in this study the software has demonstrated advanced and quick development [2].

In recent years, great potential has been demonstrated with silicon hetero-junction technology (HJT) in both exploring high conversion efficiency and up scaling towards mass production, because of its bifacial capability, low operating temperature coefficient, and relatively simple manufacturing process [3].

HJT is just one of the candidates competing to become the next generation technology for commercial PV production. And committing to fully overhauling production facilities.

HJT primarily addresses one issue associated with both standard production and many advanced cell architectures. Thin amorphous silicon layers are deposited on crystalline silicon wafers to form silicon hetero-junction solar cells. With this model, industrial manufacturing can achieve energy conversion efficiencies of more than 20% [4]. The metal contacts formed in most of the Approaches are highly recombination-active and cause losses. This can be avoided by electronically separating contacts from the absorber by insertion of a wider band-gap layer. Achieving this change is mainly what HJT is all about. Without the need of any patterning processes, the cell architecture produces exceptionally high open-circuit voltages [5].

HJT is based on a lower temperature process. Simplifies the process steps—from about 13 for PERC (Passivated Emitter and Rear Cell) to 8. It has Low degradation & Lower thermal coefficient. But, HJT requires a completely different processing sequence that has little in common with today's mainstream cell production [6].

The excellent HJT solar cell performance has already been proven to transfer into highly effective solar modules by a number of corporations (including Panasonic Corp. and Meyer Burger). A crucial measure for module producers is the cell-to-module power ratio or CTM, which is the total power of the module divided by the power of its constituent cells. The power ratio of a CTM can vary significantly depending on the module type and its features [7].

As part of the process development for the HJT, the objective is to achieve reasonable low production costs for cell manufacturing as well as high efficiency [8].

This paper presents a case study of sizing and designing a stand-alone photovoltaic system utilizing HJT solar panels. The site details and meteorological data are collected. There are two processes involved in the design of the PV system. Firstly, calculations of watt-hour demand to design the stand-alone PV system. Then, the stand-alone PV system's overall performance is determined using the PVSyst software [9].

PVSYST Description

PVsyst is considered as one of the powerful programs for designing and estimating the features of solar PV power plants' performance. By employing many of its options and built-in features, this software produces results that are almost identical to the theoretical findings. The best feature of this software is that it allows you to import data from several Mateos as well as personnel data. Moreover, this software helps us to evaluate the PV Planet's primary performance in the following scenarios: stand-alone, grid-connected, and pumping system [10].

Additionally, the amount of the generated energy is easy to calculate. The result depends on the simulation of the sizing system, and it also primarily depends on the location of the PV system, it may contain a variety of simulation factors and could be shown as daily, monthly, or hourly values. The weaknesses in the system design could be predicted by the ‘‘Loss Diagram". [11]

2. DESIGN AND METHODOLOGY

The major parts of the stand-alone PV system are represented by the PV panels, batteries, charge controller, and inverter as seen in Fig.1.

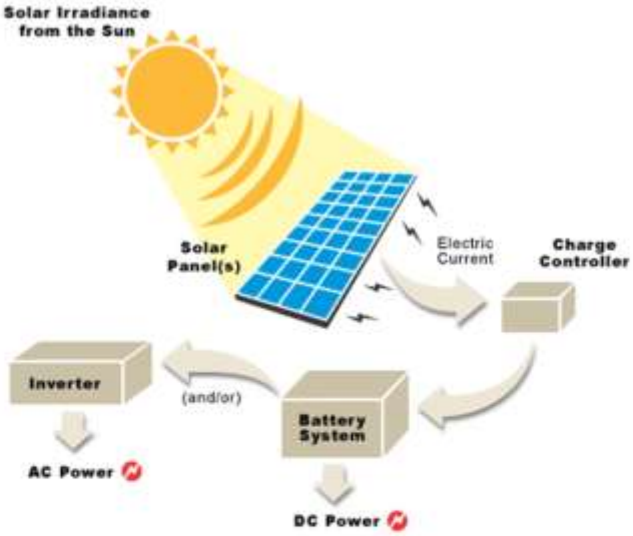


Fig.1 the parts sketch of a stand-alone system

The tilted PV panels collect the sunlight and convert it to electricity. The charge controller regulated the produced electricity. The excess electricity produced by the demand can be stored. When the sun is covered by clouds, batteries can be used as a backup during the day or at any other time. Solar panels generate DC electricity that is converted into AC electricity by the inverter to run the AC loads [12]. The layout design has been shown by the PVSYST software. See Fig.2.

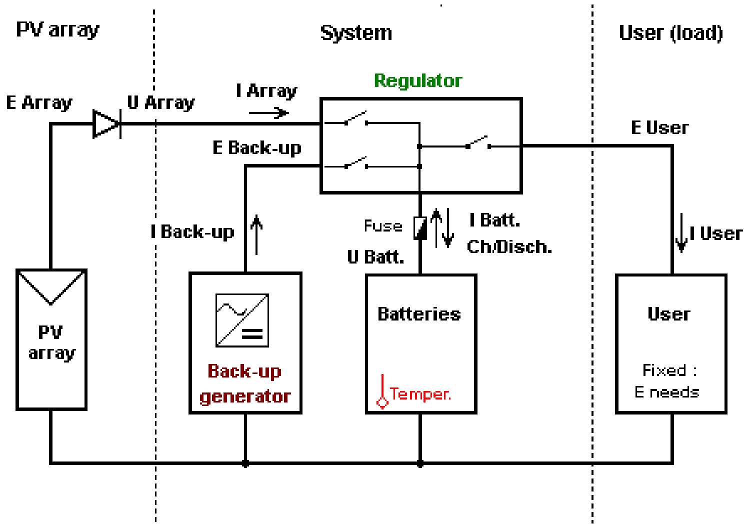


Fig.2 the System layout by a PVsyst

The solar panels are dependent on a number of factors, including PV module types, geographical coordinates, inverter quality, PV panel inclination and orientation, and battery type. [9].

3. PVsyst’s platform consists of the following:

3.1. Site coordination: In this study, a residential site has been chosen in Baghdad with latitude 33.34° N, longitude 44.40° E and 52 M altitude above the sea level as shown in Fig.3.

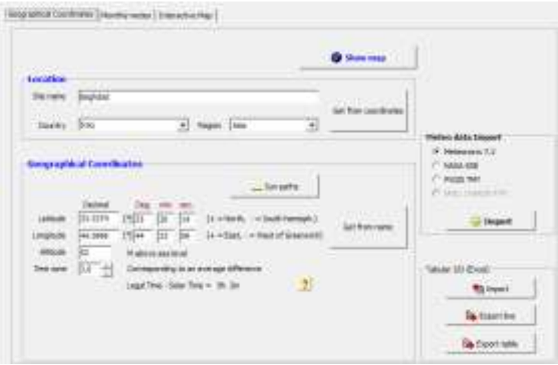


Fig.3 The site coordination with PVSYST

Baghdad has an average yearly global horizontal irradiation (GHI) which is close to 5 KWh/m²/d due to PVSYST stored database (see Table 1) [2], [10]

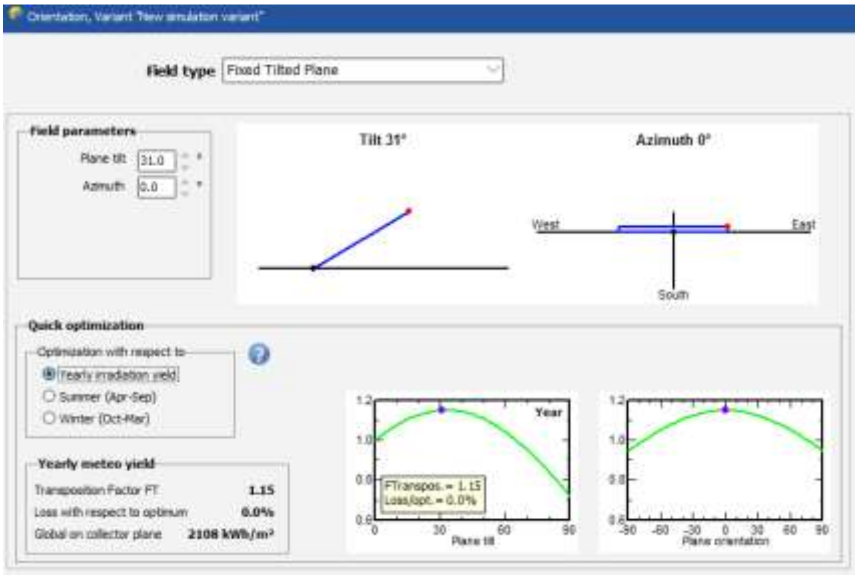
Table 1: PVSYSTS global horizontal irradiation data average

Monthly Meteo Values

Source Meteonorm 7.2 (1985-2002), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	2.72	3.62	4.80	5.64	6.38	7.11	6.98	6.51	5.75	4.21	3.25	2.51	4.96	kWh/m²/day
Horizontal diffuse	1.10	1.59	2.06	2.70	2.98	3.07	2.99	2.76	2.03	1.92	1.31	1.12	2.14	kWh/m²/day
Extraterrestrial	5.40	6.82	8.46	10.08	11.11	11.51	11.32	10.51	9.10	7.39	5.79	4.98	8.55	kWh/m²/day
Clearness Index	0.503	0.530	0.567	0.560	0.574	0.617	0.617	0.619	0.632	0.569	0.561	0.505	0.580	ratio
Ambient Temper.	7.1	10.2	14.9	19.2	25.4	30.4	33.6	33.0	27.8	22.7	13.7	8.9	20.6	°C
Wind Velocity	1.7	2.1	2.2	2.3	2.3	2.5	2.5	2.1	1.9	1.6	1.4	1.5	2.0	m/s

3.2 Tilt and azimuth angle installation: A fixed tilt plane has been set. In this model, the tilt angle and azimuth angle are 31° and 0°, respectively. This optimization with respect to yearly yield irradiation is shown in Fig.4. The system's inclination angle is known as the tilt angle. Furthermore, the azimuth angle is known as "the angle between the south/north and the collector plane" [13].



Orientation, Variant "New simulation variant"

Field type: Fixed Tilted Plane

Field parameters
Plane tilt: 31.0 °
Azimuth: 0.0 °

Quick optimization
Optimization with respect to
● Yearly irradiation yield
○ Summer (Apr-Sep)
○ Winter (Oct-Mar)

Yearly meteo yield
Transposition Factor FT: 1.15
Loss with respect to optimum: 0.0%
Global on collector plane: 2108 kWh/m²

FTranspos. = 1.15
Loss/opt. = 0.0%

Fig.4. the installation of tilt and azimuth angles

Fig.5 is shown the horizon portion and it shows the sun path and how much value the sun is really reachable. The system simulated without any shades due to the real location which the system is set.

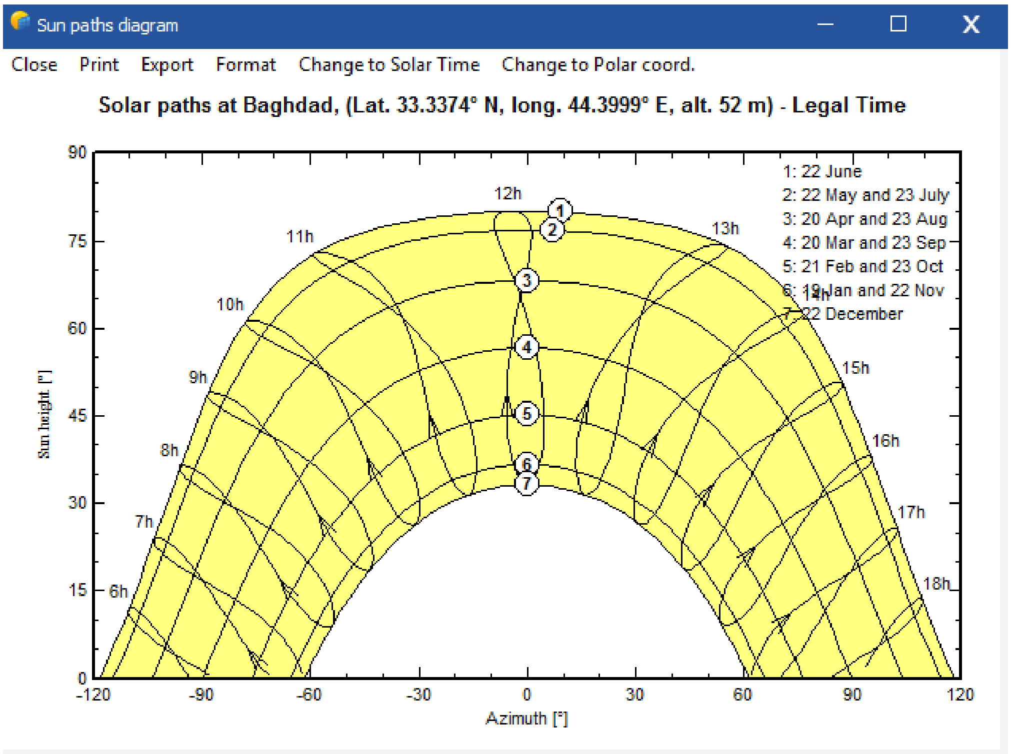


Fig.5 the sun horizon path

3.3. Load data: The energy consumption with the load data of this study is recorded in Table 2. From those details, it is discovered that daily energy consumption can reach **10 kWh**, and the peak power is close to **2 kWh**.

Table 2: Illustrates the load data consumption

Appliance	Number	Power	Daily Use
lamps	3	18 w/lamp	5 h/day
tv/pc/mobile	1	100 w/app	9 h/day
fridge	1	0.3 kwh/day	10 h/day
cloth washer	1	500 w	1 h/day
air-condition	1	1000 w/app	8 h/day
stand by consumers	1	1 w	24 h/day

3.3. The battery selection: The specifications of the selected battery has been illustrated below in Table 3.

Table 3: Specifications of the Battery

model	KBM216_2P13S 90AH
manufacture	kokam, lithium ion
total no of battery	3
voltage	48 v

battery in series	1
battery in parallel	3
total weight	102 kg
capacity	270 ah
battery pack voltage	48 v
temperature mode	fixed 20 c°
stored energy (80% dod)	11 kwh
total stored energy during the battery life	31285 kwh
number of cycles at 80% dod	3000
lifetime	5 years

3.4. Choosing an appropriate PV module: Si hetero-junction solar cells will represent the next generation of high-efficiency photovoltaic cells. HJT solar cells have achieved a conversion efficiency of 26% as a result of the successful design of the structure and the development of theory, demonstrating the high potential of Si hetero-junction technology and Targeting a simplified fabrication process [14], Because of its bifacial capability, low operating temperature coefficient, and relatively simple manufacturing process, An HJT solar cell requires excellent passivation of the c-Si surface, a process dominated by hydrogenation of silicon dangling bonds and reduction of interfacial defect density with essential amorphous silicon layers (i-a-Si:H). [3]

The software provided a list of different PV modules that can be selected according to "the panel material, panel quality, the power output, and robustness". The details of the PV modules utilized for this study have been shown below in Table 4.

Table 4: PV details and specifications

pv model	REC450AA 72
manufacturer/year	rec 2020
module power	450 wp 38v
number of strings	5
number of modules in series	1
sizing voltage	vmpp (60c°) 40.6 v voc (-10c°) 57v
temperature coefficient	-0.26 %/c°
area	11 m^2
lifetime	20 years
Max. operating power at 1000 w/m^2 and 50 c°	2.3 kw

There are several relationships between incidence irradiation and cell temperature shown in Fig 6, 7, and 8. As can be seen, increasing incidence irradiation and cell temperature are related by increasing voltage [2].

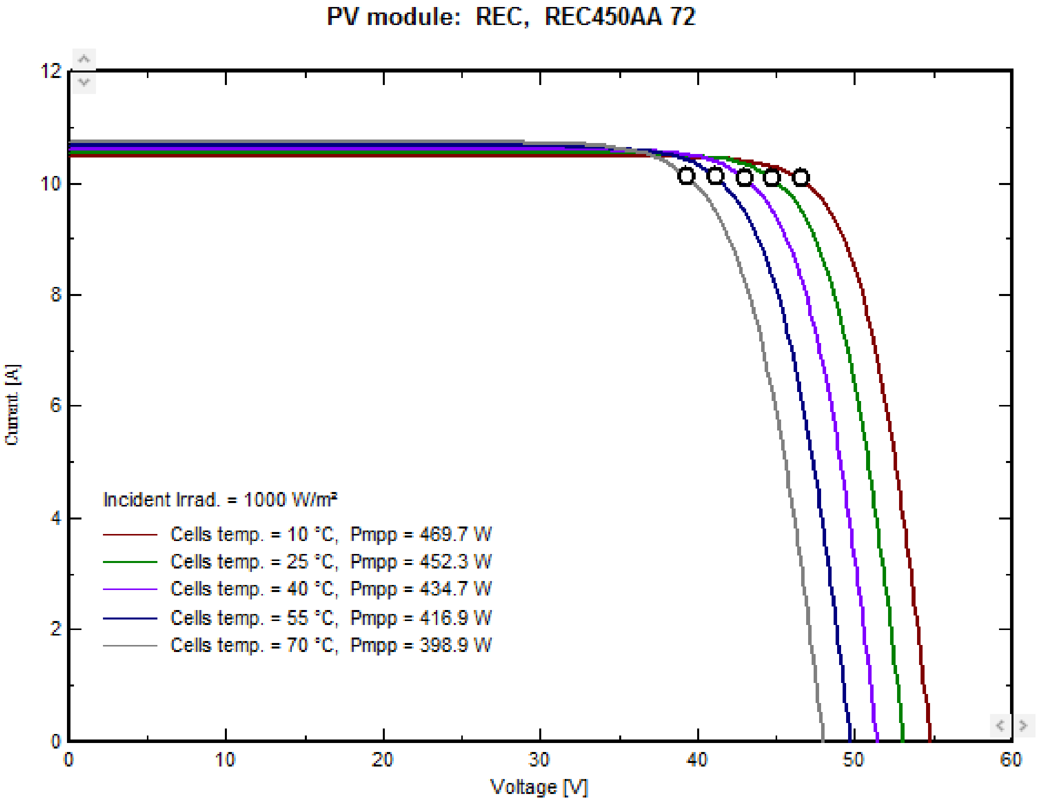


Fig.6 Current and voltage with increasing temperature

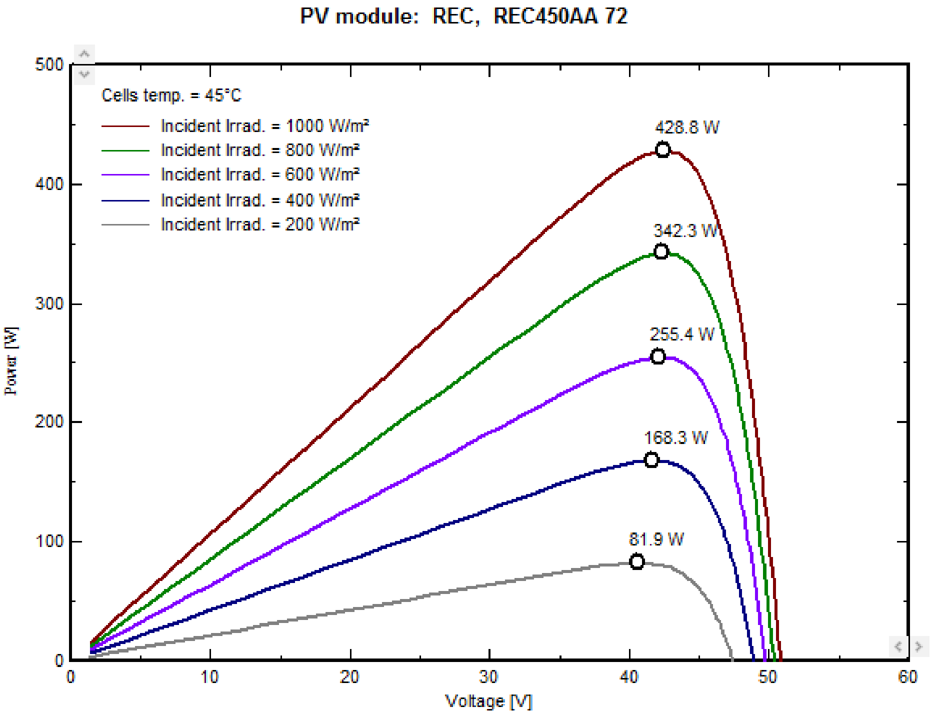


Fig.7 Power with incident irradiation of the module REC450AA 72

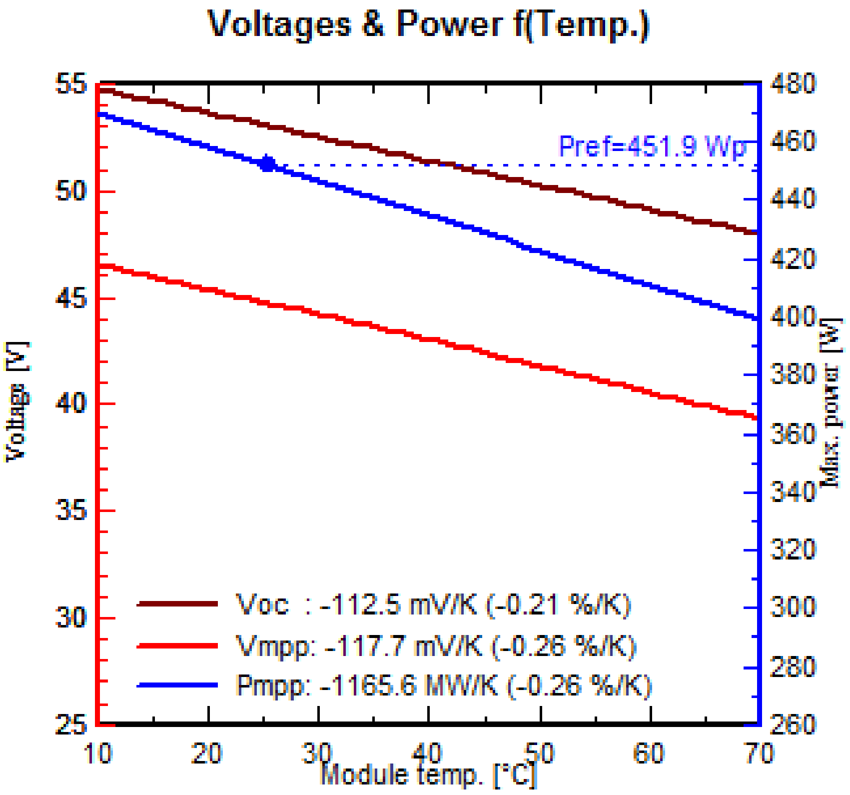


Fig.8 Voltage and power with increasing temperature

3.5. Choose the inverter: During this simulation, a stand-alone PV system was designed using the MPPT converter of 2000W and 48V with a maximum charging and discharging current of 52 A to 25 A.

For a stand-alone PV system, the inverter must be large enough to handle peak load demands [[15], [16]]. To ensure safety, the size of the motor should be 20–30% greater than the sum of the power of all running loads [17].

The inverter's size can be determined using the calculation below:
The inverter Size = Power demand × Correction factor for safety 1

For motor loads, the correction factor for safety is 3, while for simple loads, it is 1.2 [16]. The recommended inverter size, when replacing in Eq. (1), is approximately 2 kW. The inverter's output voltage is 220 volts, while it’s DC input voltage is 48 volts. Below the specification of the selected inverter is shown in Table 5.

Table 5. The specifications and electrical data for the inverter

Type	**universal controller with mppt controller**
input dc voltage	30-60 V
input dc current	52 A – 25 A

output ac voltage	48 v
nominal output power	1.8 kw
maximum output power	2 kw
no of inverters	1
efficiency	97%

According to equation (2), the inverter's efficiency ($\eta_{inverter}$) is determined by the ratio of the AC power P_{AC} output to the P_{DC} input:

$$\eta_{inverter} = \frac{P_{AC}}{P_{DC}} \qquad 2$$

Fig 9, 10. Have been illustrated curves of the Ac Input and DC Output efficiencies of an Inverter.

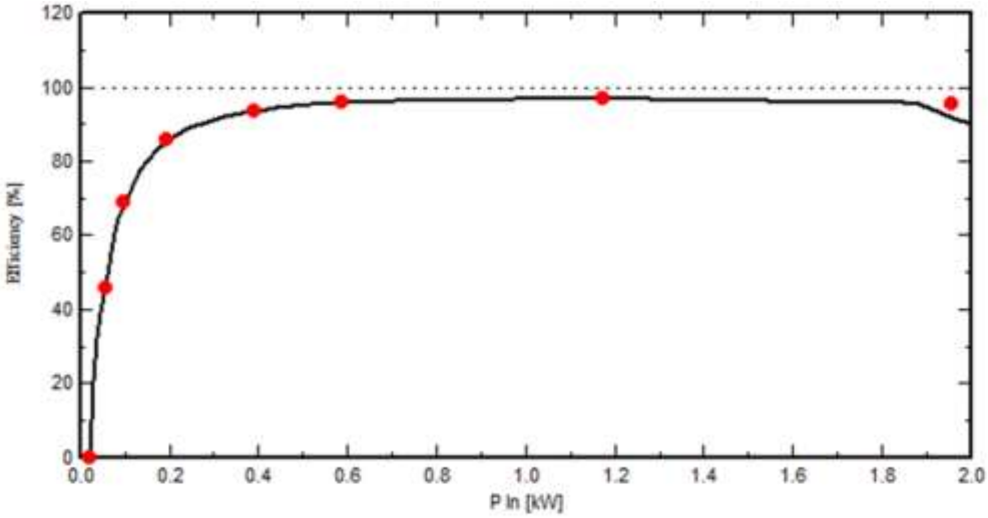


Fig .9 The Inverter AC input efficiency curve

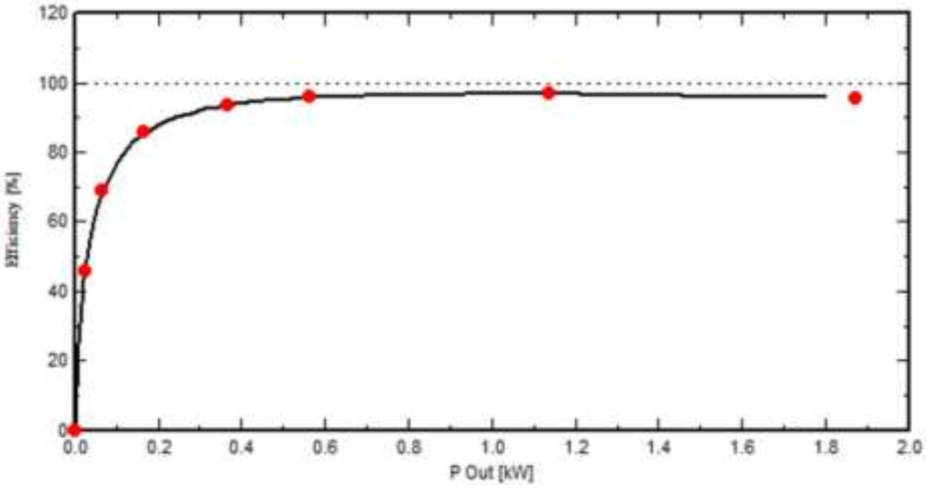


Fig .10 The Inverter DC output efficiency curve

The Objectives of the simulation design

The main objectives of the simulation in PVsyst are listed below:

- To determine whether or not it is appropriate to install a PV system at the desired location.
- Simulate the stand-alone PV system by PVsyst software.
- Specify the PV system's optimal design, output, and losses.

The optimization period could be chosen annually or seasonally, such as in the summer or the winter, but this study has been set up with an annual irradiation yield optimization.

4. RESULTS OF THE STUDY

PVsyst software is used for the proposed site. The simulation processes generate all the figures. In this paper, computational modeling has been done, hence only simulation results have been discussed [3].

Four output graphs can be taken from The simulation output are "daily input/output, performance ratio and solar fraction SF, array power distribution, array temperature vs. effective irradiance" are shown in Fig 11, the reference incident energy in the panel see Fig. 12, nominal power see Fig.13 and Detailed study of IAM (incidence angle modifier) see Fig. 14.

Efficiencies of PV modules, inverters, installations and loads have been calculated based on the system summary.

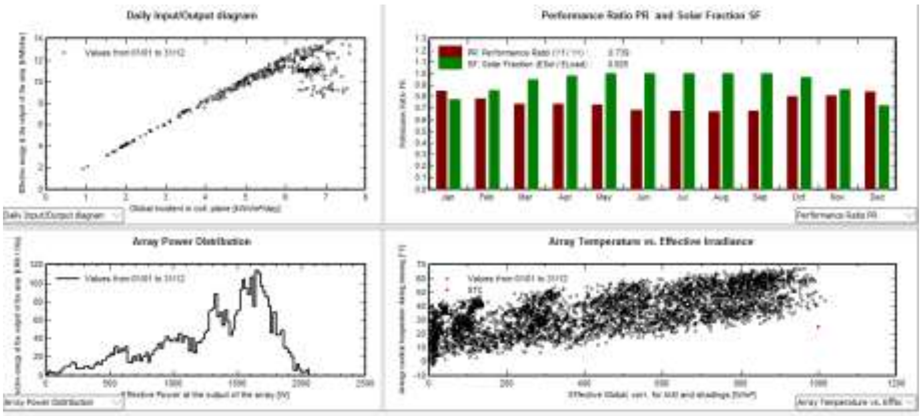


Fig 11. Array power distribution and Performance ratio.

It was found that the highest performance ratio (PR) was obtained in the months of December and January at 86% based on the low temperature of the PV modules and the lowest (PR) at 70% based on the high temperature of the PV modules. Consequently, the annual average (PR) is 73.9%. It is possible to calculate the Performance Ratio (PR) by dividing the final PV system yield (Y_f) to the reference yield (Y_r) [18].

$$PR = \frac{Y_f}{Y_r} \qquad 2$$

In terms of solar fraction (SF), there is a relationship between the amount of energy supplied to the load and the amount of energy need by the load, which is given by the function below:

$$SF = \frac{\text{energy supplied to the load}}{\text{energy need by the load}} \qquad 3$$

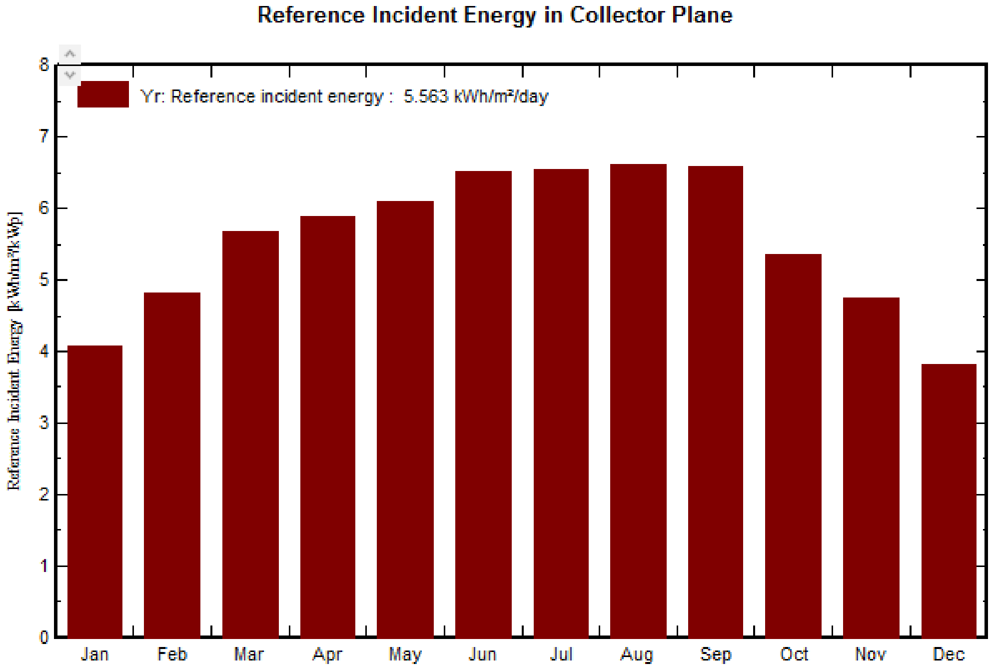


Fig. 12 Monthly reference incident energy in collector plane

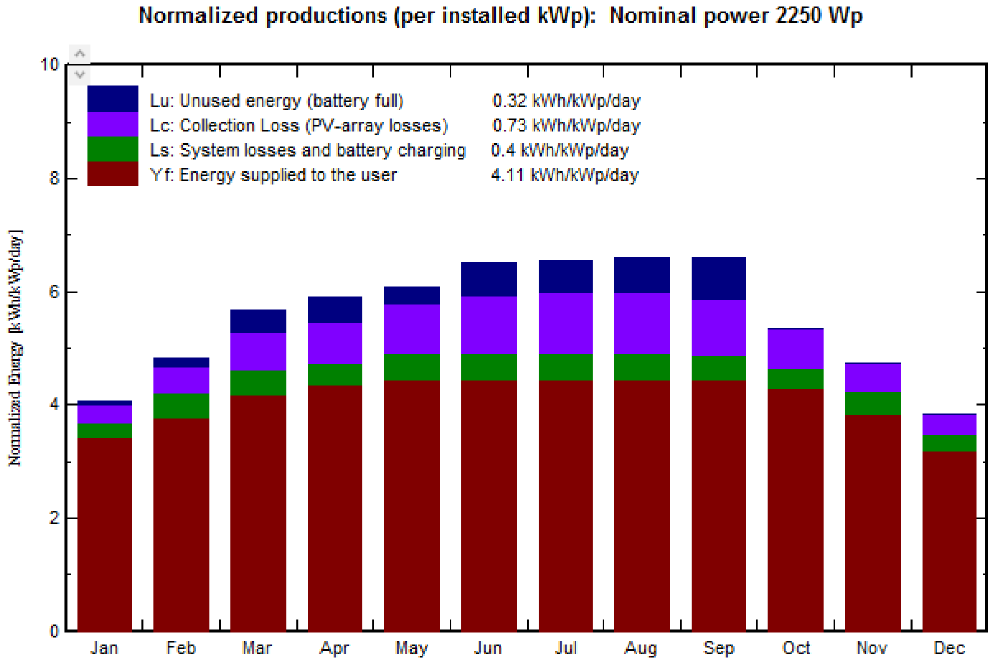


Fig. 13 Monthly Normalized Productions with losses

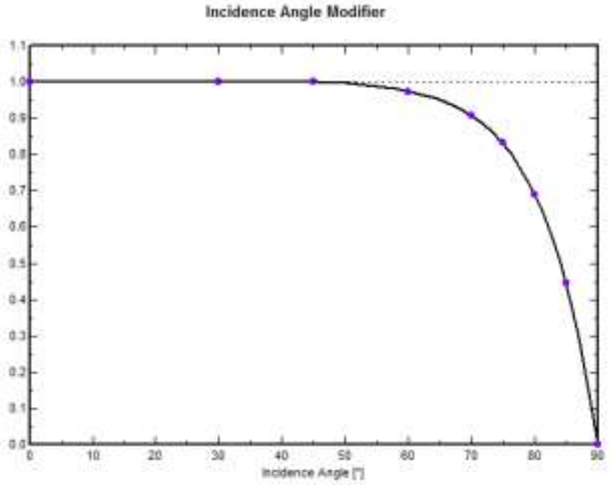


Fig .14 Detailed study of IAM (incidence angle modifier).

Fig. 15 illustrates the main characteristics of the energy losses in PV panels, including global horizontal irradiation, the global incident in the panel, nominal array energy (STC), battery efficiency, energy supplied to the user, and energy consumed by the user (load)
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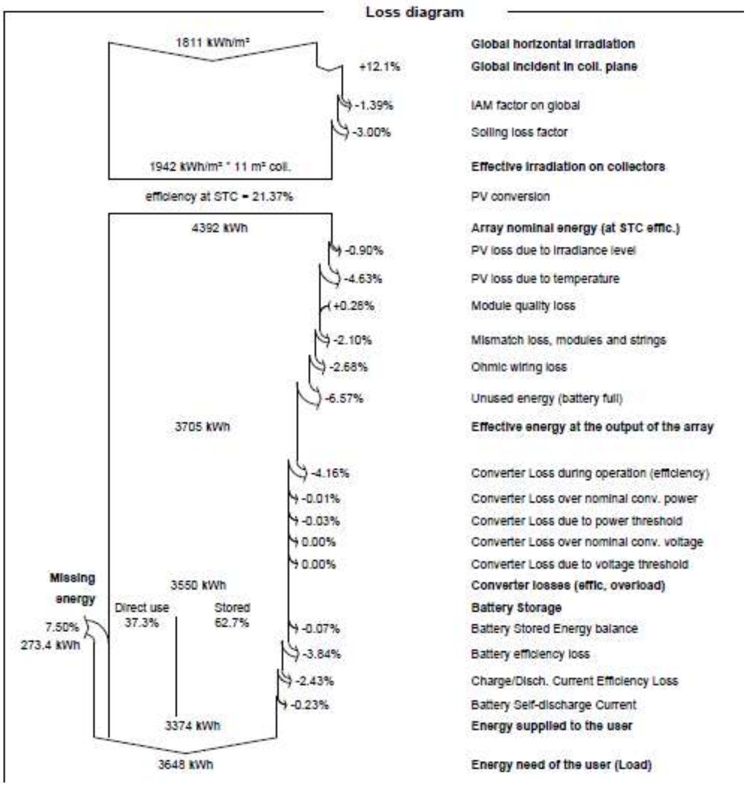

Fig. 15 loss diagram for whole year

5. CONCLUSION

The simulation of a stand-alone photovoltaic system has been performed using the PVsyst program. According to the simulation results, it is possible to determine the size of the solar panel and the type of inverter to meet the desired load demand. The site's geographic location has a significant impact on the sizing process. The diagrams for the system's performance, losses, and detailed configuration have all been produced. Utilizing the PVSyst software and watt-hour demand estimates, the PV system has been sized and theoretically simulated. The system operates at 220V AC and 48V DC. Whereas, a silicon hetero-junction technology (HJT) solar cell is a series of solar cells with passivation contacts that exhibit high open-circuit voltages (VOC), generally well above 700 mV. Having achieved an efficiency of 21.3%, this represents a new record efficiency for silicon solar cells. The bifacial nature of the HJT technology, coupled with its low temperature coefficient, should lead to record-high energy production per rated power across a wide range of climate regions. Therefore, 450W HJT panels are used in this study. It has been determined that the system needs 5 parallel panels, 1 series panel, and 5 total panels. These panels require an area of 11 m^2. The performance ratio and solar fraction from the PVSyst software are 74% and 92.5%, respectively. For the system, a 90Ah, 48V battery is selected. The system required 3 batteries overall, 3 batteries in parallel, and 1 battery in series. Additionally, it was found that the system with a single-phase, high-frequency 48V DC to 220V AC inverter (2kW, 220V) worked effectively.

This system generates a peak of 309.9kWh in May, July, and August, and a minimum of 279.8kWh in February; the nominal energy generated by the array is 4392KWh at 21.3% efficiency. Furthermore, according to PVsyst simulation results, the average yearly PR for PV plants is 73.9%, with a maximum PR of 86% in January and December, and a minimum PR of 70% in August and September.

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