https://doi.org/10.26682/csjuod.2023.26.2.47
Journal of University of Duhok., Vol. 26, No.2 (Pure and Engineering Sciences), Pp 515 - 532, 2023
4th International Conference on Recent Innovations in Engineering (ICRIE 2023) (Special issue)

A DESIGN MODEL AND COMPARISON OF FIXED AND TRACKING PHOTOVOLTAIC SYSTEMS FOR A SINGLE-FAMILY HOUSE IN ERBIL, IRAQ

HARDI K. **A**BDULLAH[*] and **P**ARINAZ **M**. **A**BDULKARIM[**]
[*]Dept. of Architecture, College of Engineering, Salahaddin University-Erbil, Kurdistan Region-Iraq
[**]Presidency of Erbil Municipalities, Ministry of Municipalities and Tourism, KRG-Iraq

(Accepted for Publication: November 27, 2023)

ABSTRACT

Solar power through the use of photovoltaic (PV) system is the most advanced and profitable renewable energy application; however, there are still a number of obstacles facing this technology, including technical, financial, and political barriers. According to meteorological data of Iraq, the annual average solar radiation is about 1800-2390 kWh/m^2/year, which is a considerable amount of energy if properly utilized. This study proposes a design model of PV installation system and the model is applied to three different PV systems for installation in a residential household in Erbil, Iraq. The study examines the feasibility of the plants proposed and compares the efficiency of both fixed and tracking PV systems for an off-grid PV system. The PVsyst software is used for household electricity load estimation and solar energy requirements, such as the appropriate number of panels, maximizing AC power generation, the storage capacity of the battery, and charge controller size to fulfill the required load. To calculate the annual energy generation, the design data was used in the simulations. Three scenarios were simulated; fixed panels, East-West single tracking, and dual-axis tracking systems based on the altitude and azimuth tracking angles. The study compared both the photovoltaic properties and the amount of energy generated by the installed systems. The results showed that the dual-axis tracking system is 30% and single-axis tracking system is 21% more efficient than the fixed PV system, although the latter offers an economically better alternative.

KEYWORDS: Renewable energy, Solar power, Photovoltaic system, Off-grid PV system, PV installation types

1. INTRODUCTION

Electricity is one of the most important drivers for the rapid economic development of countries. Accordingly, various energy sources, such as coal, natural gas, uranium, solar photovoltaics, geothermal energy, water flow, and wind, have been used to generate electricity. Traditional energy sources, such as fossil fuels, are only available in limited amounts and are responsible for global warming, earthquakes, and human health issues. Renewable energy, or clean energy, is developed from natural sources, such as solar and wind. Renewables are becoming important sources of energy production and there are currently several increasingly innovative and low-cost ways of utilizing them (Abdullah et al., 2020). Therefore, the use of these profitable sources can lead to economic development in almost every country. Solar energy generation activities do not harm our environment as no greenhouse gasses are emitted when generating electricity from solar power (Mundaca & Richter, 2015). Renewable energy is generally accessible everywhere and by everyone and offers many advantages, including: pollutant free energy sources, low or reasonable cost, sustainable sources (unlimited power source), economic development, etc. Hence, renewable energy, particularly solar power, can be profitably used to provide electricity for the heating and cooling of buildings, industrial processes, and transportation (The European Union, 2018).

There has been a continuous shortage in energy generation due to long-term political and economic crises in Iraq. Daily electricity shortages are a common problem all around Iraq, including Erbil (Abdullah & Alibaba, 2017). Erbil is the capital and most populated city in the Kurdistan Region in the north of Iraq and is located between latitudes 36.18° N and 44.01° E with an altitude of 392m above sea level. The Erbil Governorate encompasses an area of 15,074 km2, with a population of approximately 2,200,000 people (The European Union, 2018). The inability to meet electricity demand, as well

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

as the existing instabilities, have resulted in the increased use of fossil fuels; such as the diesel-based generators that are frequently used as a source of supplementary electricity generation to the main grid.

There is an average outage rotation of about eight to twelve hours of schedule cut program in Erbil. Due to this regular disconnection rotation, consumers have to pay two different bills each month; one for the consumption amount of the main grid and the other for their generators. Currently, the local government has not fully resolved the inadequacies in electricity production by employing diverse electricity generation sources since oil is an inexpensive and locally-available source of energy production. However, this phenomenon has elevated the level of greenhouse gas emissions, which negatively affects the health of citizens (Al-Douri & Abed, 2016).

Nevertheless, global warming’s severity and the sustainable development goals have necessitated the use of green energy from renewable sources, such as solar, wind, hydropower, biomass, etc. (Sobhani et al., 2014). The climatic conditions of the city, namely year-round solar radiation, support the idea of electricity generation from solar power (Abdullah et al., 2020). Advancements in technology have facilitated this goal using photovoltaic systems. A PV cell converts solar power to electricity through a systematic process, and this power generation is sustainable and green (Qadir & Saeed, 2011).

The aim of this study is to develop a design model of a Standalone (also called off-grid) solar PV system for a single-family house in Erbil, Iraq. The proposed model will be applied to design different PV system installations, including fixed, single-axis tracking, and two (dual)-axis tracking system. The study attempts to determine which of the available system installation methods is most suitable in terms of energy generation in the study location. The findings of this research offer guidelines for designers, stakeholders, and policymakers concerning PV system design and installation methods in Erbil.

2. CLASSIFICATION OF PV INSTALLATION SYSTEMS

There are two main photovoltaic panel installation systems, namely fixed and tracking systems (single axis and dual-axes tracking systems). Tracking systems accurately track the direction of the sun during the day and adjust the face of the solar panel or reflective area to track the sun's motion. The movement of solar trackers compared to fixed panels increases the amount of solar energy by up to 40% (Banerjee, 2015). However, tracking systems are considered more expensive and complex, requiring more maintenance compared to fixed PV installation.

3.1 Fixed PV Systems

The less complicated and cheapest solar panel stand is the fixed-tilt. This type of installation is fixed in position and does not track the sun through the sky during the day. The latitude of the panel site is typically equal to the faces in the direction of the southern sky at an angle. The quantity of electricity produced by the fixed-tilt photovoltaic solar system depends on the direction of the panels relative to the sun. When the rays of the sun are perpendicular to the panels, they absorb solar radiation efficiently (Perraki & Megas, 2014). Two different angles that specify their orientation related to the sun are used by fixed-tilt photovoltaic systems: the azimuth and the tilt. Latitude is also the primary factor in deciding the tilt of the panels, as tilting the panel at an angle equal to its latitude towards the south maximizes the annual exposure of the panel to direct sunlight (Karafil et al., 2015).

Therefore, in the case of not changing the angle of the fixed mount solar plane and keeping it constant, an angle equal to latitude is an efficient angle. However, the angle of the fixed mount can be changed in winter and summer. In summer, it can be changed up to 15 degrees to calculate higher sun angles. Besides, in the winter months, when the sun is lower in the sky and close to the Southern horizon, it can be set up to 15 degrees lower (Abdullah & Alibaba, 2018). Ideally, for better productivity, the tilt will be equivalent to 15 degrees less than the location’s latitude during the summer months and 15 degrees higher than the location’s latitude during the winter months. For more performance, the tilt can be manually adjusted as often as needed, but a fixed tilt mount is not changed. In the ground-mount market share, researchers argue that the less advanced fixed-tilt technology is the second-best option (Bailek et al., 2018).

3.2 Tracking PV Systems

The solar panel is aligned toward the sun by a solar tracking system. During the day, the trackers alter the position of the panels to collect the maximum amount of solar energy, these are known as sun tracking solar panels. The trackers operate towards getting the least angle of incidence; likewise, the incoming rays are nearly perpendicular to the panels. The angle reduction increases the output of energy through the panels (Banerjee, 2015). When adopting solar trackers, a few aspects must be considered, namely the type of solar technology that needs to be applied, the expected amount of direct solar radiation, feed-in tariffs in the project location, and the capital and regular maintenance cost of the system (Quesada et al., 2015).

Power provided by the decentralized applications system can be increased using a tracker. Photovoltaic systems can be very efficient by using high-efficiency panels with trackers. Therefore, it is distinguished as a single-axis tracking PV system and a dual-axis tracking PV system. Solar tracking systems are more expensive compared to fixed angle systems because of having moving parts (Hafez et al., 2018).

2.2.1 Single-Axis Tracking PV Systems

One of the sun-tracking techniques is the single-axis solar tracking system, which rotates on one axis and moves in one direction, requiring the use of a pivotal point to rotate from one side to the other side. The single-axis solar tracker usually has a manual adjustment (tilt axis) on the second axis that is adjusted at regular periods throughout the year. Also, although the axis of rotation is aligned along the northern meridian, using the advanced tracking algorithm it can be aligned in any major direction. There are several types of this system, including horizontal, vertical, tilted, and polar single-axis tracking (Seme et al., 2020).

The great disadvantage of this type of system is that it cannot track the sun during the annual motion, which means that it only tracks the sun during daily movement, and on cloudy days, due to rotation, the efficiency of the tracking system is greatly reduced. Besides, the incident radiation will not always be perpendicular to the aperture of the collector, thus solar energy collection is not adequate to sustain the maximum efficiency (Banerjee, 2015). Nevertheless, the main advantages of single-axis trackers are:

a. Single-axis trackers are simple, inexpensive, and work at a low-cost compared to dual axis trackers

b. They are more reliable

c. They have a longer lifespan

d. They are better for companies with a lower budget or zones with frequent clouds

e. They have a better performance related to a PV panel in fixed form

f. The effectuality of the single-axis solar tracker over the fixed solar tracking mount panel is more by 21% (Banerjee, 2015).

2.2.2 Dual-Axis Tracking PV Systems

A dual-axis tracking system was implemented to overcome the limitations of the single-axis tracking system. In this type of tracking system, the rays of the sun are fully captured by tracking the sun's movement in four different directions (Sidek et al., 2017). In addition to observing the East-West or North to South movement of the sun in the sky, it tracks the angular position of the sun. The dual-axis acts in the same manner as the single axis but takes the measurements of both the horizontal and the vertical axes (Abdullah and Alibaba, 2017).

Two-axis tracking enables the solar system to be more precisely focused, provides a 40% energy absorption increase, and is more complicated and expensive. Ideally, the incidence angle is always zero in the case of dual-axis tracking, in which the surface is held perpendicular to the solar radiation (Sumathi et al., 2017). To follow the sun, various manufacturers use various methods for tracking. For example, GPS signals are used by the All-Earth Renewables dual-axis trackers to determine the latitude and longitude of the tracker, as well as the date and time. Using this information, the tracker determines the position of the sun for each time and directs its orientation towards the sun using a hydraulic actuator system. Even during cloudy times, the tracker will face the sun, so when the clouds split, the tracker is already in a position to generate maximum power generation immediately. Since the panels are directly interfacing with the sun, All Earth approximations are such that its dual-axis trackers generate 45% more than a fixed-roof system and over 30% than a fixed-ground-mount system (Burnham et al., 2019).

3. MATERIAL AND METHODS

3.1 Context and Case Study

In the past fifteen years, the electricity demand has dramatically raised due to the increase in the investment projects, particularly the residential sector in Iraq (see Figure 1). Concerning the Kurdistan Region in the north of Iraq, during the period of first investment law release by KRG Board of Investment in 2006 to 2021 the construction licenses have been given to 449 different projects to be built on 9183.45-hectare land with an estimated budget of 35.26 billion US Dollars (KRG Board of Investment, 2021). Only in Erbil, the total number of residential projects, including housing and residential towers, is 185 in which the investment in residential sector corresponds to 29.20%, as outlined in Table 1. This rapid growth requires a large amount of electricity generation, conversely, the government has not a clear plan for how electricity can be supplied for these new projects.

The hot summer and cold winter climate resulted in the high demand for cooling and heating loads (i.e., 1.3 MWh per capita in 2020), while the shortage in the region's electricity sector remains one of the most pressing problems for the local government. The government provides about 8-14 hours per day in the peak seasons (KRG Ministry of Electricity, 2021), and the rest hours are supplied by private generators, which result in elevated CO_2 emissions, for reference, 4.609 tCO_2 per capita in 2020 (Crippa et al., 2021). Generating electricity from solar renewable energy is the most promising solution for the climate of Iraq, specifically Erbil. Recently, residences have shown their interest in the installation of PV system on the roof top of their houses; however, the knowledge about PV system design and analysis is not sufficient.

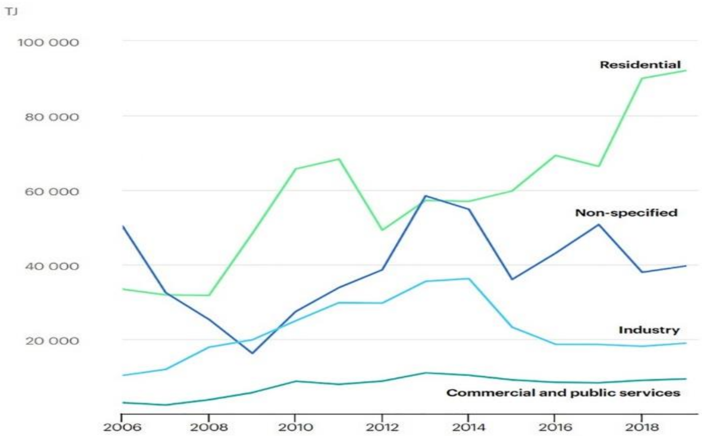

Fig.(1):- The electricity consumption by sector in Iraq during 2006-2019. Source: (IEA, 2020).

Table (1):- Investment in residential projects in Erbil, KRG, Iraq during 2006-2021. Source: (KRG Board of Investment, 2021).

Number of projects	Estimated budget ($)	Land area (Hectare)	Sector for investment
185	17,253,129,138	7121.4	29.2%

This research is limited to the installation of PV modules on the roof-top of houses in Erbil, thus the required information about the house typologies, available roof areas, and estimated electricity demands are provided through the use of field observations and data collection. There are several house types in terms of the land area and built-up area that affect the roof area for PV installation and electricity demand, for instance, 100 m^2, 150 m^2, 200 m^2, 250 m^2, 300 m^2, 400 m^2, and in some cases 500 m^2 or above. These differences are due to the situation that there are two types of housing units: one is the houses built inside investment city projects (also called walled cities) and the other is the distributed lands that individuals built their houses on according to the regulations of the local municipality. In general, those houses which are built by ordinary people are row houses attached on three sides only the elevation is open, while the cities built by companies are detached or semi-detached houses. The Ministry of Electricity supplies electricity for the residential sector based on the available area which is 40-60 watts per meter square, for instance, 8800.0 kW is provided for 200 m^2 houses, which corresponds to 8,800 kW (KRG Ministry of Electricity, 2021). Finally, the calculation method of electricity loads is described in the electrical load calculation section. The details of house types, roof areas, and estimated electricity demand are outlined in Table 2.

Table(2):- Specifications of the common house types in Erbil.

Land area (m^2)	Land dimensions (m)	Number of floors	Built-up Area (m^2)	Roof Area (m^2)	General house components	Electricity Demand (kWh/day)
100	5 x 20	2	150	75	Living r., kitchen, 3 bedrooms, 2 baths	4-6
150	7.5 x 20	2	230	115	Living r., kitchen, reception, 3 bedrooms, 2 baths	6-9
200	10 x 20	2	280	140	Living r., kitchen, reception, 4 bedrooms, 2 baths	8-12
250	12.5 x 20	2	350	175	Living r., kitchen, reception, 4 bedrooms, 3 baths	10-15
300	15 x 20	2	420	210	Living r., kitchen, reception, 5 bedrooms, 3 baths	12-18
400	20 x 20	2	520	260	Living r., kitchen, reception 5 bedrooms, 4 baths	16-24

3.2 The Proposed Design Model

This study presents a design model of PV installation system for single-family houses in Erbil, which aims at offering a practical method of generating electricity from the PV panels. In addition, it compares different photovoltaic installation methods and their performance in this specific climatic condition. Accordingly, the methods include the development of a design model and its application to a case study house in Erbil. As a design tool, PVsyst V6 software (Mermoud & Wittmer, 2014) is used to test the proposed model and consequently compare the performance of fixed and tracking (i.e., single and dual axis tracking) PV systems.

To start with the proposing a design model of PV system, numerous previous research were studied to determine the design process and the important design parameters. When designing a PV system for a particular case or building, the calculation of the electrical loads required is a necessary task (Al-Najideen & Alrwashdeh, 2017), which includes the user's needs for electricity and daily profile for a full year. Therefore, this model suggests that the electricity demand analysis should be performed in the first stage followed by the metrological data analysis of the location. Researchers have identified several design parameters that the efficiency of PV modules depends on, such as location and the availability of sunlight, type of installation design, orientation, and angles, and the selection of PV materials (el Badawe et al., 2012). Krishna et al. (2021) suggest the design parameters be determined in the process of PV design and simulation, namely solar irradiance, tilt angle, PV module type, and inverters. Similar parameters are studied in related research (Mohanty et al., 2016; Omar and Mahmoud, 2019). Other factors affecting the efficiency of PV panels include dust, cloudiness, shading, and maintenance. Based on the acquired information, the proposed model is designed in several stages as illustrated in Figure 2.

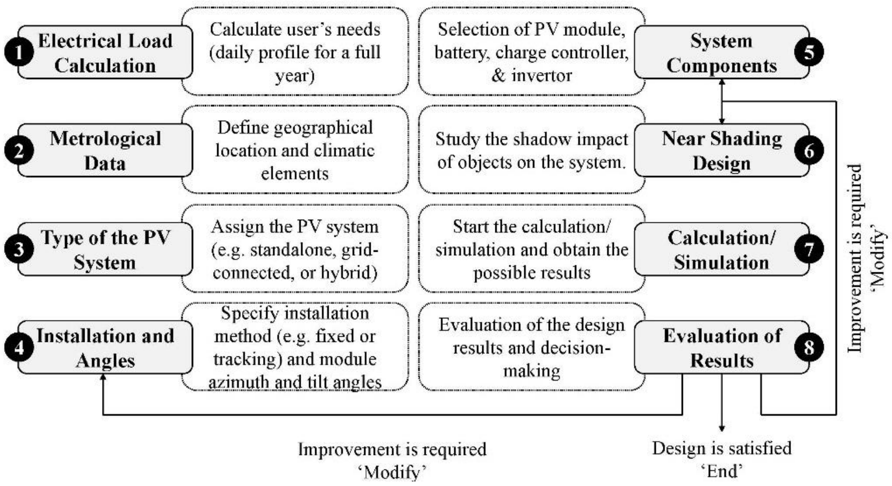

Fig.(2):-The main stages of the proposed PV design model.

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

3.3 Application of the Design Model

The proposed model will be applied to design and compare different PV system installations, including fixed-tilt, single-axis tracking, and dual-axis tracking systems for a single-family house in Erbil. PVsyst software is employed as a design and evaluation tool to apply the design model presented in this study.

3.3.1 Electrical Load Calculation

This section demonstrates a method of the household load profile calculation, particularly important electrical equipment and the actions of users. To estimate the electricity demand, a comprehensive hourly load data profile for an entire year is required. Site details, such as a load profile for regular household consumers and the time of use of electrical appliances, are the key requirements for the design of the PV system (AlShemmary et al., 2013). Using a field observation approach, the prevalent electrical equipment and duration of their use in the studied house types are identified. Then, the energy consumption demand of individual load in *Wh* (watt-hours) is calculated by multiplying the appliance's load power with its time of use as expressed in Equation 1:

$$E_i = P_i + T_u \qquad (1)$$

where, E_i represents the energy demand per day of individual load in watt-hours, P_i is the rating of individual load in watts, and T_u is the time of use of that load per day in hours.

Thus, the total energy demand in *Wh* on daily basis is calculated by adding the individual load demand of each appliance per day, as defined in Equation 2:

$$E_t = \sum E_i = \sum (P_i \times T_u) \qquad (2)$$

where, E_t refers to the total energy demand per day of all the load in watt-hours.

Accordingly, Figure 3 shows the standard house (150 m^2 – 200 m^2) annual load profile that is constant over the year and the average energy consumption at 7.627 kWh/day and Figure 4 illustrates the distribution schedule of the loads.

Daily consumptions

Number	Appliance	Power		Daily use		Hourly distrib.	Daily energy
10	Lamps (LED or fluo)	15	W/lamp	6.0	h/day	OK	900 Wh
3	TV / PC / Mobile	100	W/app	4.0	h/day	OK	1200 Wh
4	Domestic appliances	50	W/app	5.0	h/day	OK	1000 Wh
1	Fridge / Deep-freeze	0.90	kWh/day	24.0		OK	903 Wh
0	Dish- and Cloth-washer	0.0	W aver.	2.0	h/day		0 Wh
1	Heating/ Cooler (energy-efficient)	600	W/app	3.0	h/day	OK	1800 Wh
3	Other uses	150	W/app	4.0	h/day	OK	1800 Wh
	Stand-by consumers	1	W tot	24 h/day			24 Wh
	Appliances info					Total daily energy	7627 Wh/day
						Monthly energy	228.8 kWh/mth

Fig.(3):- Load calculation of daily energy consumptions for the household.

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

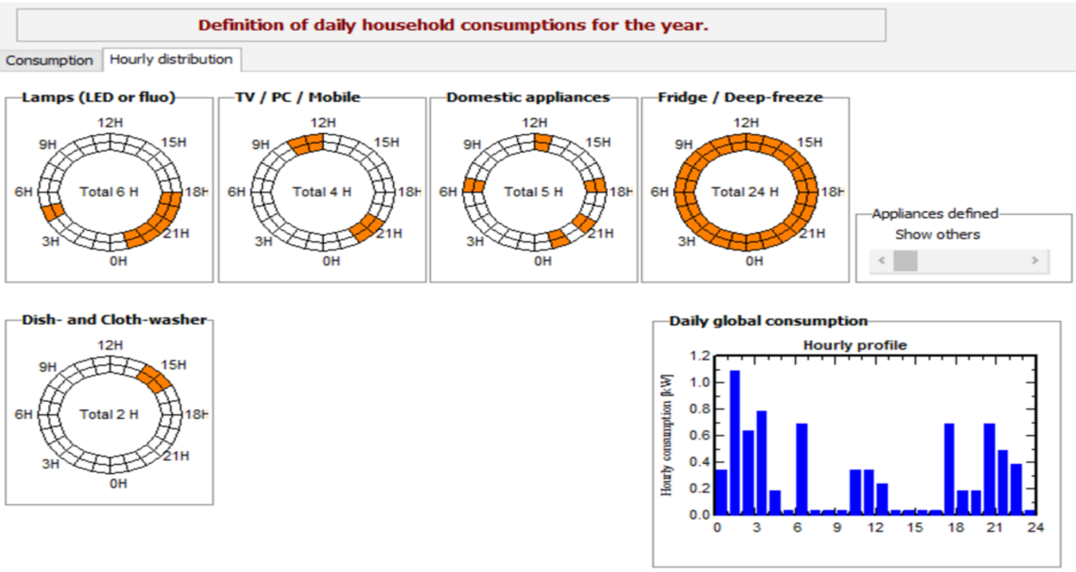

Fig.(4):- Hourly distribution of the loads.

3.3.2 Metrological Data

The appropriate site is selected based on solar radiation, which depends on the time of day and the geographical location. The housing case selected for this study is located in Erbil, Iraq (latitude 36.1833, longitude 44.0119 and altitude 392 m). The detailed data is taken from Metronome 7.3, as a part of the PVsyst tool. Figure 5 outlines the monthly global horizontal radiation, averages of the ambient temperature, horizontal diffuse radiation, and wind velocity.

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	68.4	29.6	6.8	2.20	3.922	64.7
February	86.4	42.9	8.5	2.49	4.478	63.5
March	125.6	66.0	13.1	2.59	5.307	56.4
April	150.5	83.8	17.2	2.79	7.000	54.9
May	203.0	89.7	24.1	2.79	7.000	36.6
June	211.6	87.3	30.8	3.30	5.803	23.0
July	210.5	93.1	34.8	3.19	6.181	20.9
August	195.1	79.0	33.6	2.69	5.323	23.5
September	157.4	54.3	28.3	2.49	4.711	27.0
October	117.2	50.0	22.8	1.99	4.993	37.0
November	84.3	32.9	13.9	1.89	3.897	51.8
December	67.6	32.3	8.8	2.09	3.838	62.4
Year	**1677.6**	**740.9**	**20.2**	**2.5**	**5.204**	**43.5**
	Paste	Paste	Paste	Paste		

Global horizontal irradiation year-to-year variability 4%

Fig.(5):- Determining metrological data of the case study using Metronome 7.3.

3.3.3 Type of the PV System

As stated in the aim of this study, a Standalone (also called off-grid) solar PV system for a single-family house in Erbil, Iraq is chosen in the PVsyst software to perform the PV system design and simulations.

3.3.4 Installation and Angles

The tilt angle can be adjusted depending on the position of installation and to optimize the yield of solar energy. To achieve optimum efficiency (i.e., zero losses), considering the weather and location of Erbil, the tilt angle is held around 30°, while the Azimuth angle is zero. In light of the aim of this research, three installation methods are applied, namely: fixed-tilt, single-axis tracking, and dual axes tracking, as illustrated in Figure 6.

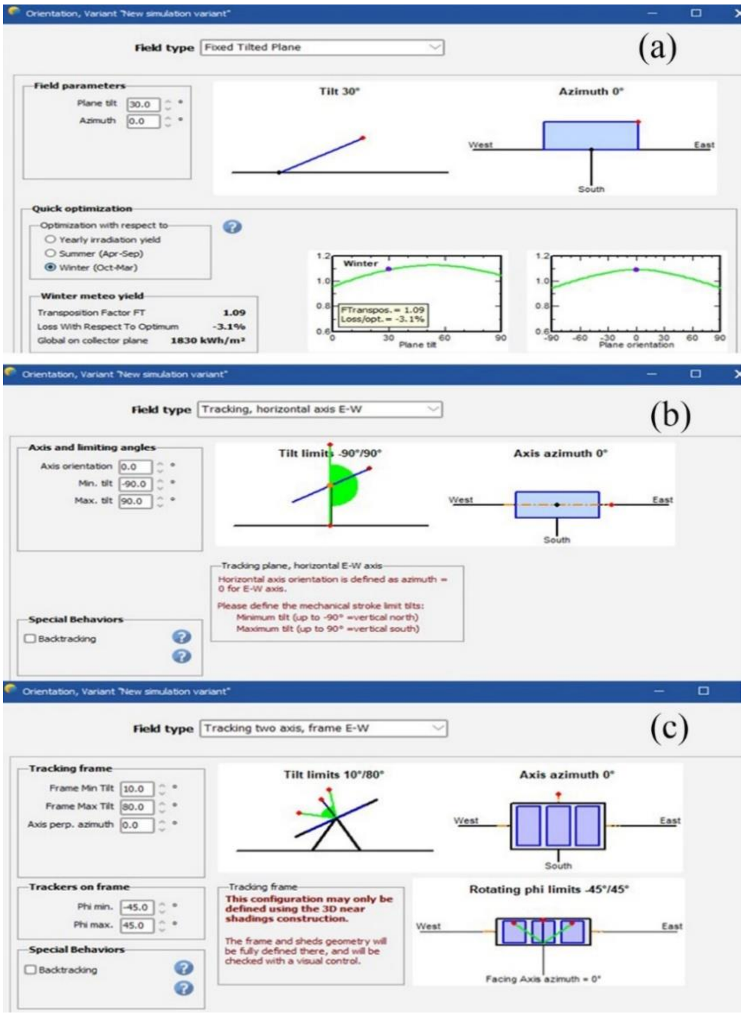

Fig.(6):- Selection of orientation for fixed installation (**a**), single-axis (**b**), and dual-axis tracking system (**c**).

3.3.5 System Components

To fulfill the system design, parameter selection is very important for system configuration. All selected components are chosen based on the energy demand as determined by the load and potential meteorological information.

PV Module Selection

There are different producers and technologies eligible to be chosen. PV array sizes depend on the available solar radiation. To build arrays, a number of solar modules are connected. To provide adequate energy for the loads and to charge the battery, the PV array must be measured correctly. To balance the system's DC voltage, which is determined by the battery, the solar panels must be calibrated. Depending on the amount of the required load, the PV size may be increased or decreased as needed. Therefore, to calculate the size and number of PV panels needed for specific loads, the rated peak-watts produced by the chosen panel is required. Thus, the total size of solar panels or PV arrays against specific load demand is calculated as (Ali, 2018):

$$P_{t-pv} = \frac{E_t}{PGF} \times 1.3 \qquad (3)$$

$$P_{t-pv} = \frac{E_t}{T_{peak-hours}} \times 1.2 \qquad (4)$$

Where, $P_{t\text{-}pv}$ represents the complete size of the PV array in watts, *PGF* represents the power generation factor, $T_{peak\text{-}hours}$ represents the lowest daily average peak-sun hours of a month in a year, the value 1.3 and 1.2 represent the scaling factor.

Hence, the number of PV modules or panels required against the total size of PV array in (3) or (4) is computed using the peak-watts of the

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

chosen panel size on market availability as:

$$N_{modules} = \frac{P_{t-pv}}{Wp_i} \qquad (5)$$

where, $N_{modules}$ represents the total number of modules, W_{Pi} represents the rating in peak-watts of selected panel or module in watts.

Based on the selected PV module characteristics outlined in Table 3 and the above equations, the software suggests that the total number of panels required for a PV array design is 12 panels.

Table (3) :-Monocrystalline (Trina_TSM_205_D80.PAN with 32V) parameters.

Parameters	Values
Length	1581 mm
Width	809 mm
Weight	14.90 kg
Cells in Series	72
Cells in Parallel	1
Immp	5.42 A
Vmmp	38 V
Voc	46.2 V
Isc	5.73 A
Power	205 W
Efficiency	16.10 %
No. of PV panels **No. of PV panels in series**	12 4 modules
No. of PV panels in parallel	3 strings
Area needed	15.3 m^2

Battery Storage

When the system is in operation, the battery charges and discharges when energy is exchanged. Various types of batteries can be included in the solar PV system, such as lead-acid batteries, lithium-ion batteries, alkaline batteries, etc. (Mahmoud, 2012; Pal & Subbra Das, 2015).

The number of batteries selected depends on the loads and cloudy (no sunlight) days, which indicates the number of days that a fully charged battery can handle system loads without any recharging from the PV array (Dunlop, 2015). Solar battery Depth of Discharge (DoD) is a very important factor to consider when selecting a battery and is expressed as a percentage of full capacity. If the battery is frequently discharged there will be fewer battery cycles to recharge it, in other words, a deeper level of discharge reduces the battery life. It is recommended that a battery is not discharged below 50% of its capacity. Important specifics to look for regarding the battery are size, *Ah* efficiency, capacity, cycle life, performance, auto-discharge rate, and space required, etc. The battery's voltage is dependent on the solar module configuration, which is between 12 and 48 volts, and the total number of *amps*. According to AlShemmary et al. (2013), the simplest relationship used to determine the size of batteries or battery banks for a certain load demand is expressed in Equation 6:

Battery Storage

When the system is in operation, the battery charges and discharges when energy is exchanged. Various types of batteries can be included in the solar PV system, such as lead-acid batteries, lithium-ion batteries, alkaline batteries, etc. (Mahmoud, 2012; Pal & Subbra Das, 2015).

The number of batteries selected depends on the loads and cloudy (no sunlight) days, which indicates the number of days that a fully charged battery can handle system loads without any recharging from the PV array (Dunlop, 2015). Solar battery Depth of Discharge (DoD) is a very important factor to consider when selecting a battery and is expressed as a percentage of full capacity. If the battery is frequently discharged there will be fewer battery cycles to recharge it, in other words, a deeper level of discharge reduces the battery life. It is recommended that a battery is not discharged below 50% of its capacity. Important specifics to look for regarding the battery are size, *Ah* efficiency, capacity, cycle life, performance, auto-discharge rate, and space required, etc. The battery's voltage is dependent on the solar module configuration, which is between 12 and 48 volts, and the total number of *amps*. According to AlShemmary et al. (2013), the simplest relationship used to determine the size of batteries or battery banks for a certain load demand is expressed in Equation 6:

$$(Ah)_{bank} = \frac{E_t}{V_{dc-sys}} \times T_{backup} \times 0.05 \qquad (6)$$

where, T_{backup} represents the total time required for backup in hours and the value of 0.05 represents the derating factor.

Thus, the number of batteries required to construct the size of the battery bank in Equation 6, is calculated using Equation 7:

$$N_{batteries} = \frac{(Ah)_{bank}}{(Ah)_{battery}} \qquad (7)$$

where, $N_{batteries}$ represents the total number of batteries required against the size of Ah_{bank} and $Ah_{battery}$ represents the capacity of a single battery in an ampere-hour. Table 4 shows the recommended battery specifications.

Table(4):-The selected battery specifications using PVsyst tool.

Battery characteristics	
Battery type	MK_Battery_8G8D_Gel.BTR
Technology	Lead-acid, sealed, AGM
Autonomy	2 days
No. of batteries in series	4
No. of batteries in parallel	7
Battery pack voltage	48 V
Global capacity	1309 Ah
Stored energy	80 % DoD
Reference temperature	20 ºC
Internal resistance	12.83 mΩ
Specific weight	36 kg

Charge Controller

In a stand-alone PV system, the main duty of the charge controller is to protect the battery from overcharging and over-discharging. Otherwise, the battery life will be shortened. It also regulates the voltage and current of PV panels and batteries and prevents the current from flowing back toward the modules. There are two different types of charge controllers: PWM and MPPT. Both technologies are great for the stand-alone solar industry and are good options for efficient battery charging, although MPPT controllers have a higher rate of energy harvesting. Table 5 outlines the attributes of the selected charge controller. Thus, the ampere size or current rating of the solar charge controller is calculated mathematically by Equation 8:

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

$$I_{sec} = I_{sc} \times 1.3 \qquad (8)$$

where I_{sec} represents the size of the solar charge controller in amperes, I_{sc} represents the short circuit current rating of the selected PV unit, and the value 1.3 represents the safety factor.

Table(5):- Outlines the recommended charge controller specifications.

Controller characteristics	
Model	Universal controller with MPPT convertor
Technology	MPPT converter
Manufacture	Victron
No. of controllers	1
Max. charging current	56.6 A
Max. discharging current	22.7 A
Converter nom. power	1968 W
Nominal output voltage	48 V
Reference temperature	20 ºC
Max. efficiency	97 %

Inverter

An inverter converts the direct current (DC) electricity from the photovoltaic array into an alternating current (AC) that can connect seamlessly to the electricity grid. Most facilities are wired for AC, so the inverter plays a critical role. The efficiency of the modern inverter can be as high as 98%. The inverter also senses the utility power frequency and synchronizes the photovoltaic-produced power to that frequency (Mohanty et al., 2016). Thus, the size of the inverter is calculated by Equation 9:

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

where, $(VA)_{inv}$ represents the rating of the inverter in volt-ampere, CF represents the correction factor for safety whose value is 3 for motor loads and 1.25 for simple loads without a motor, and $(VA)_t$ represents the total electrical load in voltampere and calculated by summation of the VA rating $(VA)_i$ of all the individual loads as:

$$(VA)_{t-load} = \sum (VA)_i = \sum \frac{P_i}{pf} \qquad (10)$$

Pf is the power factor of each load.

3.3.6 Near Shading

This section simulates the shadow impact of objects that are less than 50 m from the system. The 3D simulation can be performed using a house or tree with PV panels. It requires the architect to build 3D plans, which requires a prior understanding of the exact sizes, arrays' heights, surrounding barriers, and positions.

4. RESULTS

In order to avoid repetitions, only the results of fixed installation PV system will be presented in detail. Nevertheless, the findings and contributions of tracking PV systems will be highlighted and interpreted in the discussion section.

4.1 Results of Fixed Installation PV System

4.1.1 Balances and Main Simulation Results

Figure 7 shows the balances and main results of the system for the 205W PV panels, where annual global horizontal radiation is 1677.7 kWh/m²/year. The global effectiveness of IAM and shadings is 1838.8 kWh/m² per year. The available solar energy (E_Avail) per year is 3731.4 kWh, the unused energy (full battery) is 774.1kWh, the missing energy (E_Miss) is 0 kWh, the energy supplied to the user (E_User) is 2784.4 kWh, the energy needed for load (ELoad) is

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

2784.4kWh, and solar fraction (SolFrac) is 1.000 For 205W PV panel.

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	68.4	101.1	222.9	0.0	0.000	236.5	236.5	1.000
February	86.4	111.8	244.6	0.0	0.000	213.6	213.6	1.000
March	125.6	142.3	303.2	30.7	0.000	236.5	236.5	1.000
April	150.5	154.9	326.3	79.2	0.000	228.9	228.9	1.000
May	203.0	192.8	388.5	132.9	0.000	236.5	236.5	1.000
June	211.6	192.3	372.1	123.8	0.000	228.9	228.9	1.000
July	210.5	195.4	370.4	114.7	0.000	236.5	236.5	1.000
August	195.1	196.3	370.9	115.2	0.000	236.5	236.5	1.000
September	157.4	179.2	346.4	99.5	0.000	228.9	228.9	1.000
October	117.2	147.6	298.1	46.5	0.000	236.5	236.5	1.000
November	84.3	123.5	263.9	29.9	0.000	228.9	228.9	1.000
December	67.6	101.5	224.1	1.7	0.000	236.5	236.5	1.000
Year	1677.7	1838.8	3731.4	774.1	0.000	2784.4	2784.4	1.000

Legends: GlobHor Global horizontal irradiation; GlobEff Effective Global, corr. for IAM and shadings; E_Avail Available Solar Energy; EUnused Unused energy (battery full); E_Miss Missing energy; E_User Energy supplied to the user; E_Load Energy need of the user (Load); SolFrac Solar fraction (EUsed / ELoad)

Fig.(7):- Balances and main result of the photovoltaic system for Fixed-tilt.

4.1.2 Performance Ratio PR and Solar Fraction SF

Performance Ratio (PR) is the efficiency of the system throughout the year, which provides information about the effect of total losses of the system on the rated output. Losses include the modules, shade, dust, tilt angle, and temperature losses of the module. It describes the relationship between the PV plants theoretical and real energy outputs. There are fluctuations in system output throughout the year; although, the solar fraction shows a constant during the year. By looking at Figure 8, the annual solar fraction and performance ratios are 100% and 59.9%, respectively. It is worth mentioning that the solar fraction (ESol /ELoad) refers to the energy produced by the module to the energy fed to the load.

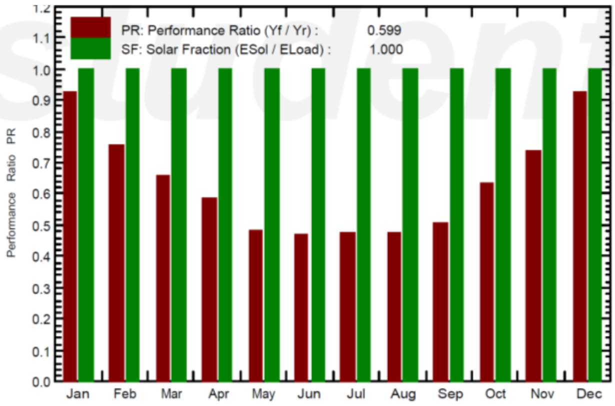

Fig.(8):- PR 59.9% and solar fraction 100%.

4.1.3 Normalized Production

Figure 9, shows the PV power plant's normalized production. It describes the unused energy, PV array collection losses, energy supplied to the user, system losses, and battery charge. It also presents the monthly output and losses per kWh. Normalized productions (per installed kWp) are evaluated from the research on simulation as shown in Figure 9. For a 205W PV panel, the unused energy (battery full) is 0.86 kWh/kWp/day, collection loss (PV-array losses) is 0.88 kWh/kWp/day, system losses and battery charging is 0.34 kWh/kWp/day, and energy supplied to the user is 3.1 kWh/kWp/day. The highest PV module losses occur in July, August, and September. In addition, the highest amount of unused energy is recorded in September and October, while September also has the most system losses.

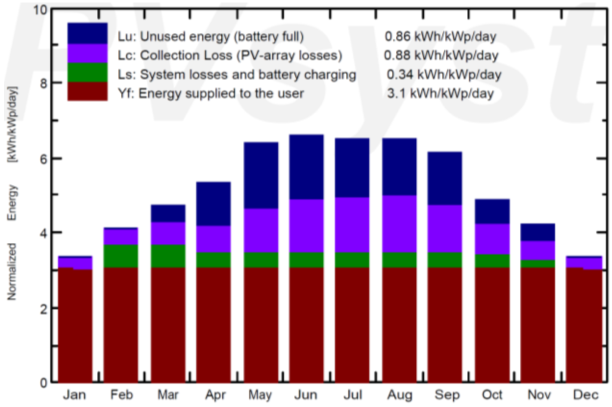

Fig.(9):- Normalized production for 280W Panel.

4.1.4 Shading Factor

Figure 10 is used to calculate the shading factor integral for the diffuse and albedo sections, and to create the ISO-shadings diagrams. It is a table with pre-calculated values at the height of the sun (Tilt =30° step) and azimuth (0° step), which is suitable for obtaining the shading factor for any sun's direction. The shaded part of the PV field is quite sensitive to the direction of the sun (values = 0 without shadow, 1 = fully shaded). Also, the blue color indicates the points (positions of the sun) located behind the area of the photovoltaic field.

Shading factor table (linear), for the beam component, Orient. #1

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
20°	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
10°	Behind	Behind	Behind	0.000	0.000	0.000	0.000	0.000	0.009	0.024	0.006	0.000	0.000	0.000	0.000	0.000	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	0.000	0.000	0.000	0.112	0.247	0.260	0.156	0.027	0.000	0.000	0.000	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.005 and for albedo: 0.150

Fig.(10):- Shading factor.

4.1.5 Shading Diagram

The PVsyst software determines the path of the sun in the sky, which comes up with details on losses that occur during the year because solar modules are unable to produce continuous electricity. The analysis of the shading factor gives an idea of how much energy is lost from the PV panels due to both near and far shading. Near shading is a partial shading affecting a portion of the panel. The shaded part changes day by day as well as during a season. For a near-shading scene, the shadow drop depends on the sun's height and the azimuth. The iso-lines (1, 5, 10, 20, and 40%) denote shading losses according to the time and date generated by PVsyst. This means that the losses due to shading are the last shading impacts that disappear every hour of the morning and the first shading effects that appear in the afternoon. The sun's motion throughout the year changes from a minimum altitude and maximum shading losses (40%) on 22nd December to a maximum altitude and minimum shading losses (1%) on 22nd June. For these calculations, the damping for diffused radiation is 0.005 and the albedo is 0.15. All actual dates in the panels for which the shading losses have been depicted are related to the second half of each month. From Figure 11, it is clear that the notion of "behind the plane" applies just to fixed arrays. The iso-shading lines are increased upward because the azimuth angle increased in the (+80°, -80°) and (+118°/-118°) bands, and especially in summer, it is close to behind the plane barrier. The fixed-tilt array experiences very small or no straight beam shading during the period from 7.00 am to 5.00 pm.

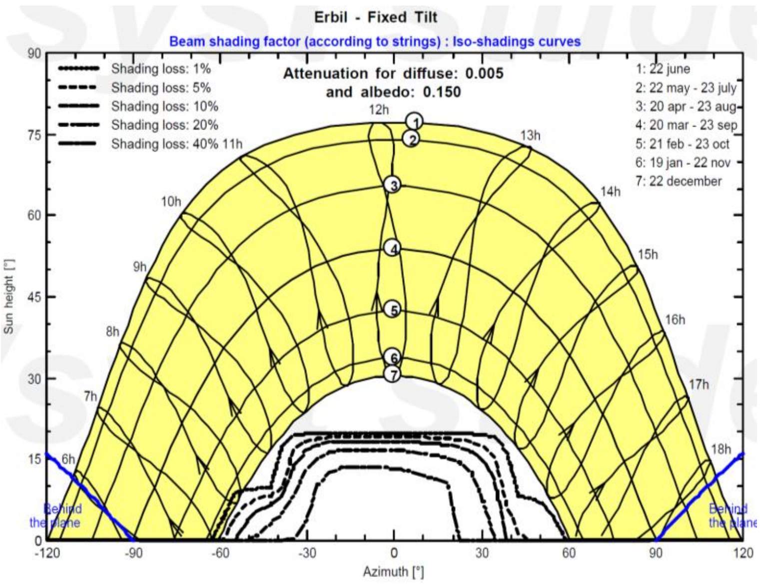

Fig.(11):- Iso-shading curve for fixed tilt.

4.1.6 Loss Diagram

This reports the system's performance with all details of losses. This diagram is useful for analyzing design choices and is used in comparing systems. The detailed over the whole year loss diagram is shown in Figure 12. The global horizontal radiation is 1678 kWh/m², the effective radiation on collectors is 1839 kWh/m² * 15 m² coll. Following the PV conversion, the array nominal energy at Standard Test Condition (STC) (1,000 watts/m², solar irradiance, 1.5 Air Mass, and a 25 °C) is 4545 kWh, and efficiency at STC is 16.10%. Effective energy at the output of the array is 3088 kWh. After the battery storage, the energy supplied to the user is 2784 kWh, and the energy requirement of the user is 2784 kWh. According to this, the missing energy is 0%. The diagram below shows that about 29.77% of the losses are accounted for as module losses, 4.24% as converter losses, and 8.7% as battery losses. In addition, the direct use of battery storage is 14.7% while stored energy accounts for 85.3%. It is observed that the highest loss occurs on the unused energy (battery full) at 20.04%.

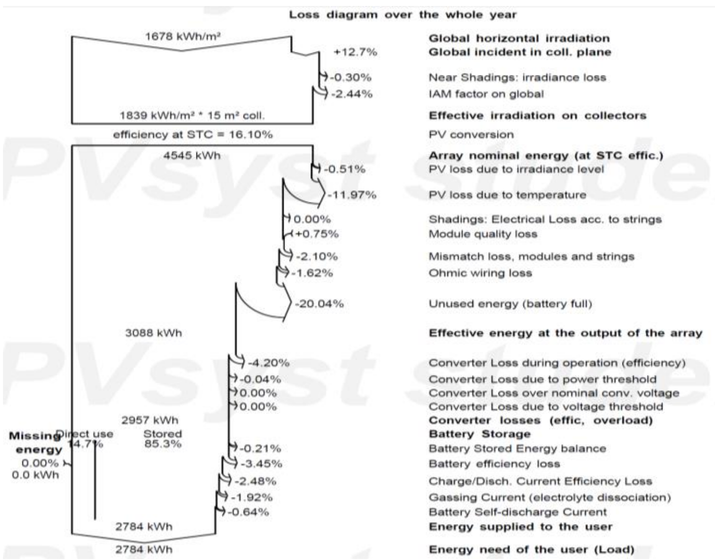

Fig.(12):- Losses diagram – fixed tilt.

5. DISCUSSION

This section compares the studied PV installations systems and interprets the results of their design applications considering the following factors (as outlined in Table 6):

- System Production, including E Load, E User, E Miss, E Unused, the excess energy injected into the grid, specific production.
- Performance Ratio PR,
- Solar Fraction SF,
- Battery storage, and
- System losses, including PV-array losses, Unused energy (battery full), PV loss due to temperature, and losses due to IAM.

PV systems are originally stand-alone systems. Each PV system is designed using the components of PV modules, charge controller, and battery, having the same types and number, with the same energy demand, same area, and a battery bank for energy storage. Tracking systems increase energy generation, but also incur extra costs to the power plant. According to the results, the yearly energy output of the fixed-tilt system, single-axis tracking system, and dual-axis tracking system are 3731.4 kWh/year, 3978.5 kWh/year, 4556.4 kWh/year; the missing energy levels are 0.00%, and the unused energy 774.1kWh/year, 1018.9kWh/year, and 1563.4kWh/year, respectively. Accordingly, the dual-axis tracking system offers a greater amount of electricity compared to other installation systems.

Comparing the losses in the systems allows some important differences to be appreciated. The differences in the results are majorly caused by differences in the representation of the losses for each system. The efficiency of the process for the three systems is 16.10%. Losses due to IAM for fixed-tilt is 2.44%, single-axis tracking is 2.04%, and dual-axis tracking is 0.07%. In contrast to the other scenarios, the lowest loss is for the dual-axis tracking system. The PV-array losses of the fixed-tilt system, single-axis tracking system, and dual-axis tracking system are 0.88 kWh/kWp/day, 0.92 kWh/kWp/day, and 1.44 kWh/kWp/day, and the unused energy (battery full) are 20.04%, 24.81%, 33.37%, respectively. The main differences between the results obtained in the systems are the temperature losses, which is 11.97% for the fixed-tilt system, 12.32% for the single-axis system, and 13.93% for the dual-axis system. The lowest value is for the fixed-tilt system, while the highest value is for the dual-axis system.

The PR obtained in the simulations for the single-axis is 56.5%, while the fixed-tilt system had the highest percentage at 59.9% and the dual-axis system the least percentage with 46.6%. SF obtained in the simulations is 100% for three scenarios. The battery loss is 8.7% for the fixed-tilt system, 8.3% for the single-axis system, and 8.27% for the dual-axis system, and the Battery Cycle's SOW "State of Wear" are around 93% and Battery Static SOW "State of Wear" are around 80% for all systems.

6. CONCLUSION

This study compared both the photovoltaic properties and the amount of energy generated by three installed systems in Erbil, Iraq: one with a fixed tilt angle, and the other fitted with solar trackers. While each system could potentially improve the amount of electrical energy produced, the literature does not contain any example of an innovative system containing the properties of all three systems, particularly in the context of Iraq. It also reviewed and compared the advantages and disadvantages of the different types of tracking systems in detail. Despite the greater popularity and lower cost of conventional fixed systems, the results of this research showed that the dual-axis tracking system is more efficient than other systems, although the single-axis tracking system offers a somewhat more economical and flexible alternative. Outlined below are the most important findings and contributions of this study:

- Following a comparative analysis of three scenarios of stand-alone solar PV systems, the study demonstrated the optimal design for a utility size stand-alone solar PV system from the study location (Erbil). It concluded that the single-axis and dual-axis tracking designs, as well as a fixed-tilt design, are viable for the solar PV stand-alone system. The PVsyst simulation tool was used to assess the performances of the different methods, which were subsequently discussed.
- Based on a comparative analysis of the various systems' daily power generation capacity, it was found that all of the systems considered were able to meet the annual power output requirements. However, the study found that the single-axis tracking and fixed-tilt systems produced less power than the dual-axis tracking system. Furthermore, the study also found that the amount of power generated was not significantly impacted by the time-based adjustments to the tilt

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com

angles of any of the schemes (fixed-tilt, single-axis tracking, and dual-axis tracking).

- Dual-axis tracking produced 30% more excess power than the fixed-tilt system, while single-axis tracking produced 21% more than the fixed-tilt system.
- The tracking systems are more costly in terms of installation, operation, and maintenance costs, relative to the fixed system.
- The conclusions drawn from the evaluation of the tracking systems and system design proposed in this study are applicable to any location for the improvement of stand-alone solar PV system performances. However, the results of the simulation depend to a large extent on the meteorological conditions of the site, load profile, and the costs of the components used at the particular location.
- The PVsyst software is a useful tool for evaluating various PV design applications by considering factors most likely to affect the performance of the PV system, including component costs, resource availability, and the load profile.

To sum up, this study contributes to the existing literature on the technical performance, economic aspects, and feasibility of solar PV with different systems. One limitation of this study was that the economic viability of renewable energy sources can be affected by the renewable energy feed-in tariff and such be analyzed further to determine its impact on a system's energy performance.

REFERENCES

Abdullah, H. K., & Alibaba, H. Z. (2017). Retrofits for energy efficient office buildings: integration of optimized photovoltaics in the form of responsive shading devices. *Sustainability, 9*(11), 2096. https://doi.org/10.3390/su9112096

Abdullah, H. K., & Alibaba, H. Z. (2018). Towards Nearly Zero-Energy Buildings: The Potential of Photovoltaic-Integrated Shading Devices to Achieve Autonomous Solar Electricity and Acceptable Thermal Comfort in Naturally-Ventilated Office Spaces. In *16th International Conference on Clean Energy* (pp. 1-11). Famagusta, North Cyprus: Eastern Mediterranean University.

Abdullah, H. K., Abdulkarim, P. M., & Karimi, H. (2020). Multifunctional Solar Façades: Impact of PV-Integrated Solar Shading on Office Energy Performance. In 6th International Conference on New Trends in Architecture and Interior Design (ICNTAD 20) (pp. 182-188).

Al-Douri, Y. & Abed, F. M. (2016). Solar energy status in Iraq: Abundant or not—Steps forward. *Journal of Renewable and Sustainable Energy, 8*(2), 025905. https://doi.org/10.1063/1.4947076

Ali, W., Farooq, H., Rehman, A. U., Awais, Q., Jamil, M., & Noman, A. (2018). Design considerations of stand-alone solar photovoltaic systems. In *International Conference on Computing, Electronic and Electrical Engineering (ICE Cube)* (pp. 1-6). IEEE.

Al-Najideen, M. I., & Alrwashdeh, S. S. (2017). Design of a solar photovoltaic system to cover the electricity demand for the faculty of Engineering- Mu'tah University in Jordan. *Resource-Efficient Technologies, 3*(4), 440–445. https://doi.org/10.1016/j.reffit.2017.04.005

AlShemmary, E. N. A., Kadhom, L. M., & Al-Fahham, W. J. (2013). Information technology and stand-alone solar systems in tertiary institutions. *Energy Procedia*, 36, 369-379. https://doi.org/10.1016/j.egypro.2013.07.042

Bailek, N., Bouchouicha, K., Aoun, N., Mohamed, E. S., Jamil, B., & Mostafaeipour, A. (2018). Optimized fixed tilt for incident solar energy maximization on flat surfaces located in the Algerian Big South. *Sustainable Energy Technologies and Assessments*, 28, 96-102. https://doi.org/10.1016/j.seta.2018.06.002

Banerjee, R. (2015). Solar tracking system. *International Journal of Scientific and Research Publications, 5*(3), 1-7.

Burnham, L., Riley, D., Walker, B., & Pearce, J. M. (2019). Performance of bifacial photovoltaic modules on a dual-axis tracker in a high-latitude, high-albedo environment. In *46th Photovoltaic Specialists Conference (PVSC)* (pp. 1320-1327). IEEE

Crippa, M., Guizzardi, D., Solazzo, E., Muntean, M., Schaaf, E., Monforti-Ferrario, F., Banja, M., Olivier, J.G.J., Grassi, G., Rossi, S., & Vignati, E. (2021) *GHG emissions of all world countries - 2021 Report*, EUR 30831 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-41546-6, https://doi.org/10.2760/173513, JRC126363.

Dunlop, J. (2015). *System Sizing. Sizing Principles, Interactive vs. Stand-alone Systems, Calculations and Software Tools.* Chapter 9. Jim Dunlop Solar.

el Badawe, M., Iqbal, T., & Mann, G. K. I. (2012). Optimization and modeling of a stand-alone wind/PV hybrid energy system. In *5th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, 1–6. https://doi.org/10.1109/CCECE.2012.6335048

Hafez, A. Z., Yousef, A. M., & Harag, N. M. (2018). Solar tracking systems: Technologies and trackers drive types–A review. *Renewable and*

Sustainable Energy Reviews, 91, 754-782. https://doi.org/10.1016/j.rser.2018.03.094

IEA (2020). International Energy Agency. https://www.iea.org/

Karafil, A., Ozbay, H., Kesler, M., & Parmaksiz, H. (2015). Calculation of optimum fixed tilt angle of PV panels depending on solar angles and comparison of the results with experimental study conducted in summer in Bilecik, Turkey. In *9th International Conference on Electrical and Electronics Engineering (ELECO)* (pp. 971-976). IEEE.

KRG Board of Investment (2021). https://gov.krd/boi-en/publications/

KRG Ministry of Electricity (2021). https://gov.krd/moel-en/

Krishna, Y., Fauzan, M. F., & Gan, N. B. M. N. (2021). Design and simulation of a rooftop PV System in Taylor's University Lakeside Campus. *Journal of Physics: Conference Series*, *2120*(1). https://doi.org/10.1088/1742-6596/2120/1/012035

Mahmoud, M. (2012). Design and Simulation of a Photovoltaic System with Maximum Power Control to Supply a Load with Alternating Current (Doctoral dissertation). An-Najah National University, Nablus, Palestine.

Mermoud, A. & Wittmer, B. (2014). PVsyst User's Manual PVsyst 6.0. https://www.pvsyst.com

Mohanty, P., Muneer, T., Gago, E. J., & Kotak, Y. (2016). Solar Radiation Fundamentals and PV System Components. In P. Mohanty, T. Muneer, & M. Kolhe (Eds.), *Solar Photovoltaic System Applications. Green Energy and Technology* (pp. 7–47). Springer, Cham.

Mundaca, L., & Richter, J. L. (2015). Assessing 'green energy economy' stimulus packages: Evidence from the US programs targeting renewable energy. *Renewable and Sustainable Energy Reviews*, 42, 1174-1186. https://doi.org/10.1016/j.rser.2014.10.060

Omar, M. A., & Mahmoud, M. M. (2019). Design and simulation of a PV system operating in grid-connected and stand-alone modes for areas of daily grid blackouts. *International Journal of Photoenergy*, vol. 2019, 5216583. https://doi.org/10.1155/2019/5216583

Pal, M., & Subbra Das, A. (2015). Analytical Model for Determining the Sun's Position at All-Time Zones. *International Journal of Energy Engineering*, *5*(3), 58-65. https://doi:10.5923/j.ijee.20150503.03

Perraki, V., & Megas, L. (2014). Single axis tracker versus fixed tilt PV: experimental and simulated results. In *the 29th European Photovoltaic Solar Energy Conference* (pp. 2711-2714).

Qadir, K. W., & Saeed, M. A. (2011). Study and analysis of global and extraterrestrial solar radiation over Kurdistan Region-Iraq. In *3rd International Scientific Conference of Salahaddin University-Erbil* (No: S-165).

Quesada, G., Guillon, L., Rousse, D. R., Mehrtash, M., Dutil, Y., & Paradis, P. (2015) Tracking strategy for photovoltaic solar systems in high latitudes. *Energy Conservation and Management*, 103, 147-156. https://doi.org/10.1016/j.enconman.2015.06.041

Seme, S., Štumberger, B., Hadžiselimović, M., & Sredenšek, K. (2020). Solar Photovoltaic Tracking Systems for Electricity Generation: A Review. *Energies*, *13*(16), 4224. https://doi.org/10.3390/en13164224

Sidek, M. H. M., Azis, N., Hasan, W. Z. W., Ab Kadir, M. Z. A., Shafie, S., & Radzi, M. A. M. (2017). Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control. *Energy*, 124, 160-170. https://doi.org/10.1016/j.energy.2017.02.001

Sobhani, M., Zakeri, S., & Taghizadeh, M. M. (2014). Review on renewable energy, sustainable energy, and clean energies. *Technical Journal of Engineering and Applied Sciences*, *4*(3), 120-123

Sumathi, V., Jayapragash, R., Bakshi, A., & Akella, P. K. (2017). Solar tracking methods to maximize PV system output–A review of the methods adopted in recent decade. *Renewable and Sustainable Energy Reviews*, 74, 130-138. https://doi.org/10.1016/j.rser.2017.02.013

The European Union (2018). Sustainable Energy Action Plan (SEAP). Kurdistan Region of Iraq, Erbil Governorate. https://www.climamed.eu/wp-content/uploads/files/Iraq_Erbil-Governorate_SEAP.pdf

Table(6):- Summary of the main study findings.

Characteristics	Discussion	Fixed-tilt system	Single-axis tracking	Dual-axis tracking
E Load (kWh)	The energy need of the user	2784	2784	2784
Available energy (kWh/year)	The yearly energy output of the system	3731.4	3978.5	4556.4
E User (kWh)	The energy supplied to the user	2784.4	2784.4	2784.4
E Miss	Missing Energy= Eload - Euser	0.0%	0.0%	0.0%
Excess (unused) - (kWh/year)	This energy is the extra energy that cannot be used when the battery is full.	774.1	1018.9	1563.4
Specific prod. (kWh/kWp/year)	It refers to the amount of power (kWh) generated for any (kWp) of module capacity during a normal or actual year.	1517	1617	1852
PV-array losses (kWh/kWp/day)	PV system converts solar radiation on PV cells into electrical energy, which eventually converts into electricity after going through various stages and different sources, thereby resulting in power loss. Main losses include radiation level, array pollution, a decrease of module quality, loss of array mismatch, ohmic losses of AC, DC and, a small number of transformer losses.	0.88	0.92	1.44
Unused energy (battery full)	In fact, at this time, we have less unused energy, while safekeeping the battery charged and using the remains of the production by PV. However, pending the next night, the battery discharge to a less extent than if it is discharged in this part, this means that you will be fully charged the next day and accordingly we have more unused energy.	20.04%	24.81%	33.37%
Performance Ratio PR	The PR is expressed as a percentage and describes the relationship between the real and theoretical energy output of a PV power plant, and is described as a quality factor. The following factors can influence the PR value: Environmental factors, PV module temperature, Solar radiation and power loss, PV module in the shade or dirt. Other factors include: Recording period, Conduct losses, Performance coefficient of PV modules, Measurement orientation	59.90%	56.6%	46.6%
Solar Fraction SF	Solar fraction depends on many factors, such as the load, collection and storage sizes, operation, and climate.	100%	100%	100%
efficiency at STC	For photovoltaics, voltage and current can be measured and multiplied together to obtain output power, which is subsequently divided by the area of the module and the power of sunlight per square meter to achieve efficiency. STC is the radiation of 1 kW/m2, the cell temperature is 25°C, and no wind.	16.10%	16.10%	16.10%
PV loss due to temperature	As mentioned in chapter 2, the PV module's characteristics are determined at an STC of 25 degrees, by considering the temperature factor of the 280 Wp modules chosen, the module efficiency reduces by -0.40% for any °C increase in cell temperature. The temperature loss of the module is computed by considering the location's temperature profile according to the Meteo database. Since the position is located in Erbil, a high-temperature region, high-temperature losses are obtained.	11.97%	12.32%	13.93%
Battery Cycles SOW "State of Wear"	Dynamic wear due to the No. of cycles. Dynamic aging mode as discharge current function and discharge depth for this hour can be accurately performed. Stored in the SOWCycl variable.	93.3%	93.7%	93.5%
Battery Static SOW "State of Wear"	Static wear due to the age of the battery. The static aging mode decreases as a function of the actual battery temperature defined by the gainer for the simulation. This is stored in the SOWStat simulation variable.	79.80%	79.80%	80%
Battery losses	The range of solar batteries' lifespan is between 5 and 15 years. Tips to extend battery life: correctly configuration with size and number of batteries, battery equalization, rotate the batteries, use large interconnection cables for battery, keep cooling, shorten the charging period and charge properly, check the condition of the solar battery regularly and keep battery power	8.7%	8.3%	8.27%
losses due to IAM	IAM (Incidence Angle Modifier) is related to the reduction of radiation reaching the PV cell due to the refraction of the sun's rays while passing through the anti-reflection coating of the PV module and glass. The higher the angle of the incident (depending on the position of the sun), the greater the losses.	2.44%	2.04%	0.07%

hardi.abdullah@su.edu.krd
parinazmuhamad@gmail.com