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Article

Applicability of solar systems with various technologies and sun-tracking: A case study of Baghdad, Iraq

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ABSTRACT

The installation of a photovoltaic system is becoming increasingly attractive to consumers in residential areas due to higher electricity tariff rates and less dependence on local power generators in Iraq. Consequently, the paper's main objective is to determine the applicability of solar photovoltaic (PV) systems in the capital city (Baghdad) of Iraq. Additionally, this study aims to find suitable PV technology and sun-tracking system for building applications in Iraq. To obtain this aim, the PVGIS simulation tool is used. It has been found that the selected city is suitable for installing PV systems in the future because of the high value of solar radiation. Furthermore, the results indicated that CdTe technology has the highest performance compared to the crystalline and CIS PV technologies. Moreover, it is observed the two-axis system has the maximum energy generation compared to vertical and include systems. This study provides useful details regarding installing a PV system in Iraq to solve the electricity crisis in the country and reduce fossil fuel consumption.

1. Introduction

In recent years, energy consumption and demand have increased due to the growing population and number of construction [1]. The increase in fossil fuel consumption leads to an increase the greenhouse gas emissions and air pollution [2, 3]. The high consumption of electricity has prompted researchers to determine an alternative energy source to decrease the environmental and energy effects of using fossil fuels [4, 5]. Many researchers have stipulated that utilizing renewables such as solar and wind energy as energy sources has helped to mitigate greenhouse gas emissions [6]. Solar energy is one of the most promising renewable energy. It is clean energy and environmental-friendly energy source. Solar energy can be converted into electrical power using solar PV. Recently, the utilization of solar PV systems as power generation for the building is becoming more and more popular generally in urban cities because of the lack of enough ground area [7]. Iraq is one of the rich countries in natural resources, as it contains the fifth-largest oil reserves worldwide and ranks thirteenth in global gas reserves. Presently, energy production, particularly electricity power in Iraq depends on fossil fuels. The electrical power crisis is one of the most important issues that affect the daily lives of citizens, small businesses, and shop owners, which have been at the forefront of daily life in Iraq for years. Therefore, the exploitation of renewables such as solar power as sources of energy can be an alternative solution to solve the country's electrical power crises [8-11]. Many studies have focused on solar energy in different locations in Iraq [12-15]. For instance, Al-Nimr and Al-Shohani [12] analyzed the solar energy output of three sites (Mosul, Baghdad, Al-Hammar lagoon) in Iraq based on solar radiation and ambient temperatures data. The authors concluded that the Al-Hammar lagoon was a suitable place for installing solar photovoltaic (PV) power systems compared to other regions. Jallo [13] assessed the potential of utilizing solar PV electricity in Iraqi houses. The author concluded that Iraq had excellent potential for generating electricity using a PV system and the PV system is an attractive alternative solution to improve family life in the country. Al-Waeli and Al-Asadi [15] analyzed the utilization of the standalone PV system in the desert of Iraq. The results demonstrated that the system can provide the necessary energy for the citizen in the desert. Based on the previous studies, this study aims to evaluate the applicability of solar PV systems in the capital city (Baghdad) of Iraq and to compare the performance of PV systems with different PV technologies and sun-tracking systems. Additionally, this study aims to find suitable PV technology and sun-tracking system for building applications in Iraq.

2. Material and Method

2.1 Study area

Baghdad is located in the northern regions of Iraq, at latitude 33.34 and longitude 44.40, at an altitude of 41m above sea level. It is located on the Tigris and Euphrates rivers, about 300 miles from the country's southern and western borders. It is the largest city in Iraq, and it is the city of the most densely populated neighboring region in the Middle East. The climate of the selected city is characterized by being cold and humid in winter and hot and dry in summer. The average temperature between May and September reaches 40℃. In winter, the average temperature during the day is 10℃. Additionally, the rain begins in December to April and averages 150 mm annually. The selected location is a residential building with a rooftop area of 100 m^2. Figure 1 displays the location of the selected city.

Figure 1. Iraq map [15]

2.2 Grid-connected PV system

The grid-connected PV system consists of solar panels, an inverter, a power conditioning unit, and grid connection equipment. The grid-connected PV systems consist of PV panels for supplying the energy demand during the daytime and are connected to the local electrical grid for power at night. Besides, the excess power from the PV system is fed to the grid when the generated power is more than the required load. Figure 2 illustrates the components of the grid-connected PV system. Based on Ref. [16-18], the essential factors that should be considered for designing the PV system are:

Power generating factor (PGF)

$$PGF = \frac{SI \times SH}{STCI} \quad (1)$$

Energy demand (ED)

$$ED = ECAL \quad (2)$$

Solar PV energy required (SPVER)

$$SPCER = PER \times ELS \quad (3)$$

PV module sizing

$$TWPR = \frac{SPVER}{PGF} \quad (4)$$

$$PVMS = \frac{TWPR}{PVOPR} \quad (5)$$

Inverter sizing (IS)

$$IS = PER \times FS \quad (6)$$

where SH is the sunshine hours, SI is solar irradiance, TWPR is total watt peak ratting, STCI is standard test condition irradiance, PVOPR is PV output power rating, ECAL is the energy consumption of all loads, SPVER is solar PV energy required, PGF is panel generation factor, PVMS is PV module size, FS is the factor safety, PER is peak energy requirement, ELS is energy lost in the system and the factor safety is 1.3.

In addition, the buildings that can generate power from solar are referred to as PV power stations. The PV panels can be integrated to the roof or façade of the building to produce electricity. In general, the PV system is categorized into building applied photovoltaics (BAPV) and building-integrated photovoltaics (BIPV) [19]. In BAPV, the panels are attached to the buildings using the additional mounting structure and moving rails [20]. In BIPV, the modules are integrated within the building structures, mainly into the roof or façade [21]. The description of the BAPV and BIPV can be found in Ref. [22]. Figure 2 shows the schematic view of both systems.

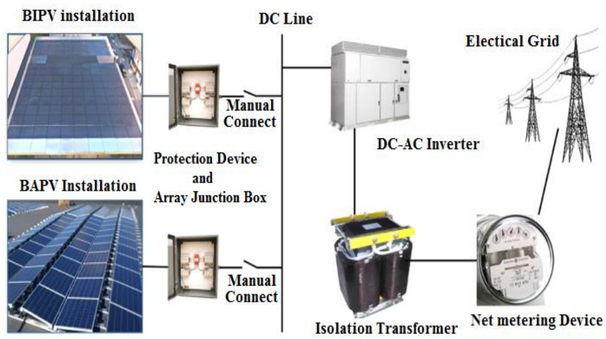

Figure 2. Schematic view of grid-connected BIPV and BAPV system

2.3 Modelling of the proposed systems

In the present study, a PV geographical information system (PVGIS) was employed to estimate the performance of the proposed 6.4 kW grid-connected BAPV and BIPV systems PVGIS is an online simulation tool. It uses to compute the energy generation of the PV system [23]. Besides, it provides a large and accurate solar radiation-free database worldwide [23]. Several scientific researchers have utilized the PVGIS simulation tool for estimating the energy generation of a PV system [19, 24-26]. Figure 3 depicts the framework of the simulation study using PVGIS carried out on the 6.4 kW solar PV system.

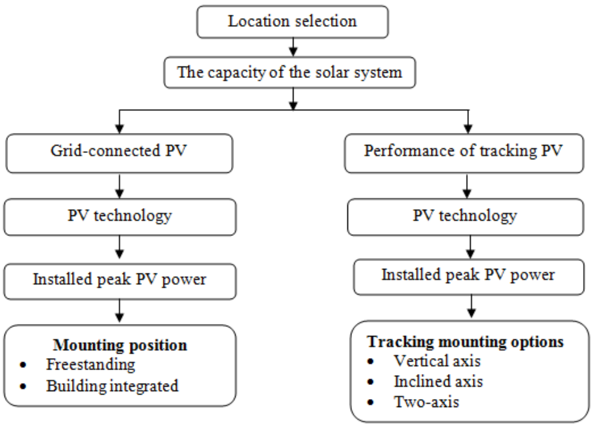

Figure 3. The framework of the simulation study using PVGIS

3. Results and Discussion

3.1 Solar resource potential

The solar irradiation (SI) and air temperature (AT) data, obtained from PVGIS are shown in Figure 4. It is found that the mean monthly value of SI is within the range of 89.46-242.02 kWh/m2. The maximum and minimum value of SI is recorded in July and December, respectively. Furthermore, the annual value of SI is estimated to be equal to 1982.87kWh/m2. According to Ref. [27, 28], the solar resource in the selected city is categorized as class 5 (excellent). Hence, it can be concluded that the selected city is suitable for installing a PV system because of the high value of SI. Additionally, it is observed that the AT values varied from 10.97℃ and 38.33℃ as shown in Figure 4.

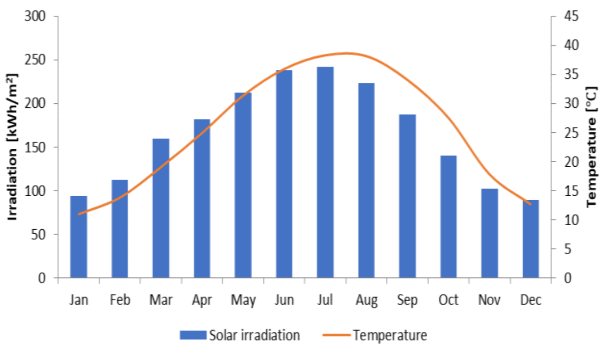

Figure 4. Monthly variation of solar irradiation and air temperature

3.2 Variations of energy generation for proposed systems for Fixed-tilt PV system

Figure 5 demonstrates the monthly variation of the proposed systems with a variation of PV technologies (crystalline, CIS, CdTe technology). It should be noted that the optimum slope and azimuth angles were found to be 31° and -14°, respectively. These angles were estimated using the PVGIS simulation tool. It can be seen that the maximum and minimum possible energy were recorded in August (1010.49kWh) and December (728.16kWh) for the crystalline-based Free-Standing system. The same crystalline panels under the same climatic condition installed as the Building-Intraged system produce the highest energy of 964.4kWh in August and the lowest energy of 699.06kWh in December. For CIS modules, the possible energy production is within the range of 707.25-1022.92 kWh and 692.97-995.58kWh for PV systems installed as Free-Standing and Building-Integrated systems, respectively. Moreover, the monthly energy production varied from 724.44-1086.96kWh and 713.84-1064.98kWh when the system was simulated as a Free-Standing and Building-Integrated system with CdTe technology, respectively. In the comparison with PV technologies, it is noticed that the energy generation is considerably higher for CdTe technology compared to other PV technologies. Additionally, it is observed that the Free-Standing system has higher energy production with various PV technologies compared to the Building-Integrated system because of the fewer losses in the system.

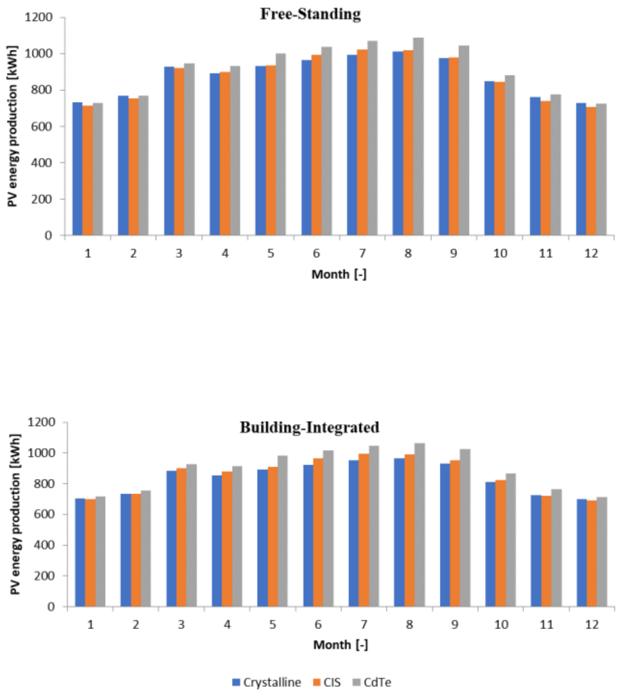

Figure 5. Monthly variation of PV energy production with various PV technologies

3.3 Variations of energy generation for proposed systems for various tracking mounting positions

The monthly energy production for different PV technologies and sun-tracking systems is illustrated in Figure 6. It should be noted that the optimum slopes for vertical and include systems were found to be 50° and 32°, respectively. It is found that CdTe technology has the highest performance compared to the crystalline and CIS PV technologies. Moreover, it is observed the Two-axis system has the maximum energy generation compared to vertical and inclined systems. These observations have been found in previous scientific studies [29-31].

3.4 Comparison of simulation results for all proposed systems

Table 1 in the Appendix summarizes the annual energy production, solar radiation, system losses for various PV technologies, and sun-tracking systems. It is found that the maximum energy production is achieved by a Two-axis PV system with CdTe technology. Moreover, it is observed that the angle of incidence losses is varied from -2.5% to -1.45%. These losses of energy have occurred in the form of current or heat. Additionally, it is found the spectrum effect losses is ranged between -0.42% and -0.36%. It should be noted that this loss will influence energy conversion. Furthermore, the temperature is considered a crucial parameter that substantially affects the PV system performance. In general, the PV panel temperature gradually increases above the air temperature of the selected location. It can be seen that the CdTe panel has the lowest influence because of changes in irradiance and temperatures compared to CIS and crystalline modules.

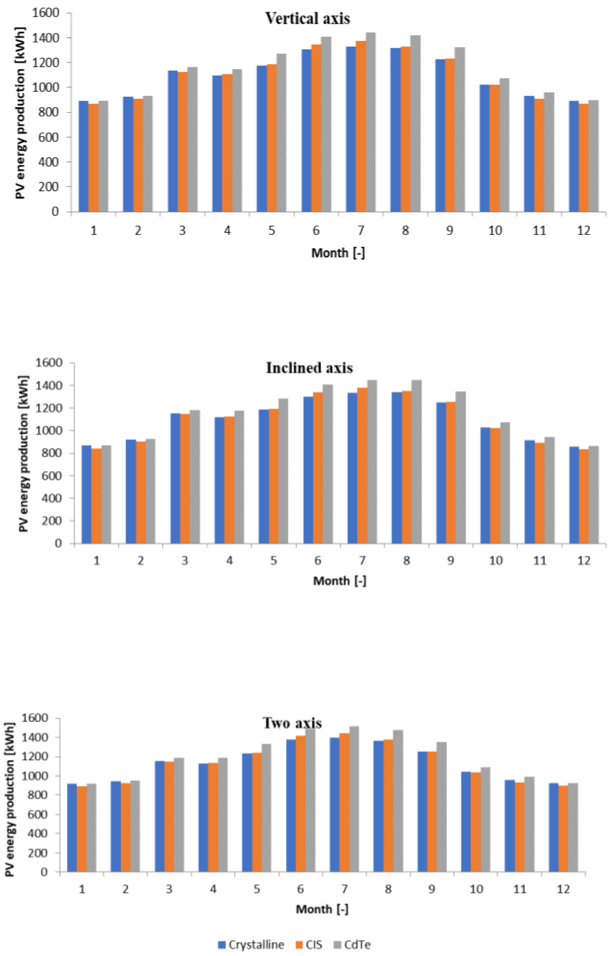

Figure 6. Monthly variation of PV energy production with various PV technologies and sun-tracking systems

4. Conclusion

In the present study, a 6.4 kW PV system with different PV technologies and sun-tracking systems is simulated using the PVGIS simulation tool to estimate the energy production under the weather condition of Iraq. Based on the solar radiation data, it is found that the selected city is suitable for installing PV systems in the future. Furthermore, the results confirmed that CdTe technology has the highest performance compared to the crystalline and CIS PV technologies. Moreover, it is observed the Two-axis system has the maximum energy generation compared to vertical and inclined systems. This study provides useful details regarding installing a PV system in Iraq to solve the electricity crisis in the country and reduce the consumption of fossil fuels. In future work, a techno-economic PV system with various technologies, capacity, and sun-tracking should be investigated.

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Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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Appendix

Table 1. Simulation output for all developed PV system

PV technology	Parameter	Free-Standing	Building-Integrated	Vertical axis	inclined Axis	Two-axis
Crystalline	Slope angle [°]	31	31	50	32	-
	Azimuth angle [°]	-14	-14	-	-	-
	Yearly PV energy generation [kWh]	10532.12	10072.27	13247.65	13276.01	13682.89
	Yearly in-plane irradiation [kWh/m²]	10532.12	2225.42	2786.07	2793.06	2885.46
	Changes in output due to					
	The angle of incidence [%]	-2.5	-2.5	-1.53	-1.52	-1.45
	Spectral effects [%]	-0.36	-0.36	-0.4	-0.41	-0.42
	Temperature and low irradiance [%]	-11.5	-15.36	-11.91	-11.95	-12.21
	Total loss [%]	-26.05	-29.28	-25.7	-25.73	-25.91
CIS	Slope angle [°]	31	31	50	32	-
	Azimuth angle [°]	-14	-14	-	-	-
	Yearly PV energy generation [kWh]	10520.14	10261.43	13265.69	13294.33	13694.7
	Yearly in-plane irradiation [kWh/m2]	2225.42	2225.4	2786.02	2793.05	2885.46
	Changes in output because of					
	The angle of incidence [%]	-2.5	-2.49	-1.53	-1.52	-1.45
	Spectral effects [%]	NAN	NAN	NAN	NAN	NAN
	Temperature and low irradiance [%]	-11.91	-14.08	-12.15	-12.19	-12.5
	Total loss [%]	-26.14	-27.95	-25.6	-25.63	-25.84
CdTe	Slope angle [°]	31	31	50	32	-
	Azimuth angle [°]	-14	-14	-	-	-
	Yearly PV energy generation [kWh]	10994.38	10796.51	13925.67	13960.95	14399.72
	Yearly in-plane irradiation [kWh/m2]	2225.43	2225.42	2786.13	2793.12	2885.46
	Changes in output because of					
	The angle of incidence [%]	-2.5	-2.49	-1.53	-1.52	-1.45
	Spectral effects [%]	-0.36	-0.36	-0.38	-0.38	-0.38
	Temperature and low irradiance [%]	-7.61	-9.28	-7.43	-7.44	-7.65
	Total loss [%]	-22.81	-24.2	-21.9	-21.9	-22.02