Indonesian Journal of Electrical Engineering and Computer Science
Vol. 26, No. 1, April 2022, pp. 184~193
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v26.i1.pp184-193

Performance comparison between fixed tilt angle and solar tracking systems at Basra governorate: A case study

Ismaeil R. Alnaab[1], Harwan M. Taha[2], Zainab A. Abdulwahab[3], Mohammed Salah Al-Radhi[4]
[1]Department of Polymers and Petrochemical Engineering, Basra University for Oil and Gas (BUOG), Basra, Iraq
[2]Technical College of Engineering, Duhok Polytechnic University (DPU), Duhok, Iraq
[3]Rumaila Operating Organization, Basra Oil Company, Basra, Iraq
[4]Budapest University of Technology and Economics, Budapest, Hungary

Article Info

Article history:

Received Sep 16, 2021
Revised Jan 9, 2022
Accepted Feb 14, 2022

Keywords:

Power production
Solar angles
Solar power
Solar radiations
Sun path

ABSTRACT

Theoretical calculations and online system simulations using PVWatts and global solar atlas simulators, were conducted in this study to find the difference in solar power production between fixed solar power systems and tracking systems at Basra Governorate. The research included the analysis of geographical location and weather conditions and their effect on output power. The reliant power resource types and power generation of the southern region of Iraq as well as load demands were demonstrated and discussed in this research. Furthermore, the sun path, solar angles and solar radiations were considered in this study, in addition to the mathematical calculations of optimum tilt angles. The methodology used in this study was based upon theoretical and online measures of real-time weather factors, solar angles, solar radiations and model properties of the examined system. The results and factors of different systems including: peak sun hours per day, dc to ac derate factors, tilt angles, solar radiations and power production were compared to multiple similar research elements that were accomplished around the same region and some other countries. The study concluded that solar tracking system absorbs more radiations and produces an annual production of 15–30% higher than fixed tilt angle system.

Corresponding Author:

Ismaeil Raad Alnaab
Department of Polymers and Petrochemical Engineering, Basra University for Oil and Gas (BUOG)
Garmat Ali, Basra, Iraq
Email: Ismaeil.r.alnaab@buog.edu.iq

1. INTRODUCTION

The importance of electricity in our modern world can hardly be overstated. A hundred years ago, what was a luxury is now a critical component to safety, prosperity, and well-being of nearly everyone. Since the inception of energy, engineers have been devising new methods of generating electrical power. In recent years, engineers started focusing on producing green energy, which means making electricity from non-conventional sources, for example, the sun. Sun is not the only natural resource we have, yet it is an essential source of renewable energy and the cleanest environment [1], [2].

Since solar power innovation in the late 1880s, scientists and engineers have worked tirelessly to develop the solar energy acquisition mechanism. In recent years, countries began to invest more in the field of solar energy than ever before. These countries share similar goals, including the trend towards a non-polluted green environment and sustainability, as such energy will not produce any greenhouse gases or other harmful by-products [2].

Iraq, which is considered one of the countries rich in solar energy, is a new entrant in this field. The geographical location of Iraq and its dry, sunny climate during most of the year, especially in the western and southern regions, makes it among the inevitable areas to go towards renewable energy [1], [3]. Another reason Iraq is looking to move towards renewable energy is the fear of running out of fossil fuels (oil and gas), which are the primary resources for producing electrical energy in Iraq [1], [2]. Furthermore, the unstable economic and political situation in Iraq encouraged investment owners to head in this direction.

While the world is on a technology rush, Iraqi people are still suffering from power outages in most areas of Iraq, which causes a considerable loss to the projects owners. Which led them to turn to alternative ways of producing electric power, such as backup generators, that uses petroleum derivatives as a resource to generate electricity. Unfortunately, having electricity using this method is more expensive than using the national grid electricity and the noise and pollution that it causes to the environment. Therefore, there is no better way than heading towards renewable energy, where resources can never be runout.

As stated before, solar energy is an essential source of renewable energy. Researchers have to be devising new methods and equipment to improve the performance of producing electrical power from solar radiations. They also investigate and optimize the solar systems under different conditions, including physical, environmental, weather and econiamic conditions. Taha and Hameed [1] optimized the tilt angle of a photovoltaic (PV) system to get the maximum generated power at Duhok city in Iraq. The authers used photovoltaic geographical information system (PVGIS) simulator an online free solar photovoltaic energy calculator to investigate 50 KWp PV system performace of different PV system technologies, which were crystalline silicon, copper indium selenide (CIS) and cadmium telluride (CdTe). The authers concluded that the monthly optimum tilt angle is equal to 30° in summer and above 50° in winter for Duhok city, north Iraq. Al-Sayyab *et al*. [2] did theoretical calculations and experimental investigation of PV cell performance to get the optimum tilted angle for Basra city in Iraq. The authers used an experimental test rig and the tilt angle was changed manualy across a range from 0° to 90°, they concluded that the yearly optimum tilt angle is equal to 28° for Basra city, south Iraq. Al-Waeli *et al*. [3] studied the impact of Iraq climate condition on solar energy applications in Iraq, including the impact of temperature, wind, humidity and dust. The authers sugest the use of photovoltaic thermal (PVT) cells or hybrid solar collectors to make use the heat produced by solar panals in other applications and thus increase the efficiency. According to Drury *et al*. [4] made a performance comparison between fixed-tilt and tracking photovoltaic systems. The authors conclude that two-axis tracking system increases the PV generation by 30 to 45% relative to fixed tilt systems. Mustafa *et al*. [5] proved by an investigation made on a test rig, that the overall generated power of the two-axis tracking system is higher by 35% than the fixed-angle system.

This study investigates a performance comparison between two types of solar power generation techniques: a fixed solar system and a two-axis solar tracking system. The study was conducted at Basra city, which is located in the southern region of Iraq. The objectives of this study can be summed up by the following points:

- Pointing out the reasons behind switching towards renewable energy in Iraq.
- Studing solar path and obtaining solar angles for Basra governorate.
- Finding the difference in solar power production between fixed solar power systems and tracking systems at Basra governorate.
- Studding the effect of weather factors upon power production and efficiency of PV systems.

This section briefly introduced Iraq's national electricity network deficiencies, an overview of solar energy, and a literature review. The second section outlines the research method used in this study. Section three presents the results and discussion. Whereas section four summarises the outcomes of this study.

2. RESEARCH METHOD

In this section, it is explained the geographical location and climate change in Iraq. The amounts of energy generated from power stations of the southern region of Iraq the analysis of sun path and solar angles for Basra city for wenter and summer seasons. Furthermore, this section will demonstrate the methodology used to find the difference in power production and efficiency for both fixed tilt angle systems and tracking systems.

2.1. The geographical location and weather conditions of Basra governorate

Basra governorate is located in the southern region of Iraq. The area's topography is semi-flat, overcome by desertification, with little greenery surrounding the Shatt al-Arab river. Basra's climate is hot and humid during summer, cool and slightly rainy in winter, as it is close to the Arabian Gulf [6], [7]. The summer season of Basra governorate is characterized by its extended daylight, which exceeds 14 hours, while it is around 10 hours in the winter season [6], check Figure 1. The temperature could reach a maximum of 50° celsius during Jun and July and around a minimum of 2° Celsius during December and January [6], [8].

Humidity reads a high percent during summer, especially in areas near the Arabian Gulf [6], [8]. It is worth noting that the summer season of Basra governorate is interrupted by stormy and dusty winds at varying times, which have effects that will be mentioned later.

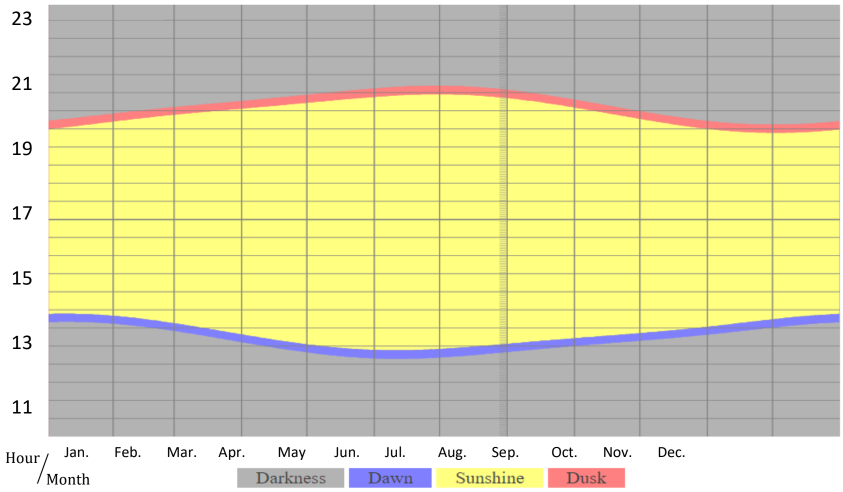

Figure 1. Daylight hours of Basra governorate

2.2. Amounts of energy generated from power stations of the southern region of Iraq

The southern region of Iraq generates around 4800 MWh from more than ten power stations distributed around the rural areas of three main cities: Basra, Amarah, Samawah and Nasiriya [9]. Gas and Thermal power stations are the two common types of plants used to generate power in the southern part of Iraq [9], check Table 1. Basra governorate individually demands around 3300 MWh. The amount of power generated is insufficient to overcome the demand, which is expected to be increased to about 4000 MWH in summer 2023, check Table 2 [9].

Table 1. Power system and generation of the southern region of Iraq

Power plant name	Abbreviation	Generation in MWh
Hartha Thermal Power Plant	HRTP	150.4
Rumila Gas Power Plant	RMLG	895.5
Najibiya Gas Power Plant	NJBG	229.8
Khur-Alzubair Gas Power Plant	KAZG	311.6
Rumila Investment Gas Power Plant	RMIG	567.4
Shatt Al-Arab Gas Power Plant	STBG	764
Nasiriya Thermal Power Plant	NSRP	255.5
Nasiriya Gas Combined Power Plant	NSGC	303.9
Samawah Gas Combined Power Plnat	SMGC	279.4
Amarah Gas Power Plant	AMRG	366.2
Zubair Gas Power Plant	ZPPG	280
Shu'aiba Gas Power Plant	SHBG1	140
Amarah diesel power plant	STX	110
	MRN	
Others	-	117.1
Thermal power production		406.5 MWh
Gas power production		3967.4 MWh
Diesel Power Production		390.3 MWh
Overall power production		4770.8 MWh

Table 2. City load

City name	City load in MWh
Baghdad	4146
Mousel	768.1
Samawah	489.4
Nasiriya	1335.9
Amarah	558.3
Basra	3212.7

By summing the "City Load" of the four mentioned cities (Basra, Amarah, Samawah and Nasiriya) and subtracting the summation from the total generated power of the southern region, the power deficiency can be found:

– Power generation of the south part of Iraq=4770.8 MWh
– Total load of the south part of Iraq=5596.3 MWh
– Power deficiency of the southern region of Iraq=825.5 MWh

Increasing the number of power plants and/or units will not solve the issue. The actual and convenient solution of this issue is to turn towards renewable energy. According to Andy Walker from the US-based national renewable energy laboratory, the cost of operation and maintenance (O&M) of solar systems is declining year after year compared to conventional power plants [10]. In addition to other benefits it provides, the lack of need for the significant number of employees, the lack of demand for operating fuel, and the lack of need for huge power transmission lines.

2.3. Sun path and solar angles

As already known, the sun path from sunrise to sunset is not the same throughout the year, and this will lead us to deduce that the solar panels have to be placed in various tilt angles. The Sun path diagram in Figure 2 per day for Basra city is shown in Figure 2(a). Figure 2(b) and 2(c) show the side view of the sun path diagrams per day for winter and summer seasons individually [11], [12].

The orange ball represents the summer sun, while the yellow one represents the winter sun. The centre point of the circle, denoted by letter C represents the centre of Basra city, for example. The coloured triangles toward the centre represent the sun's outgoing radiations, and the red line represents the tilt of solar panels.

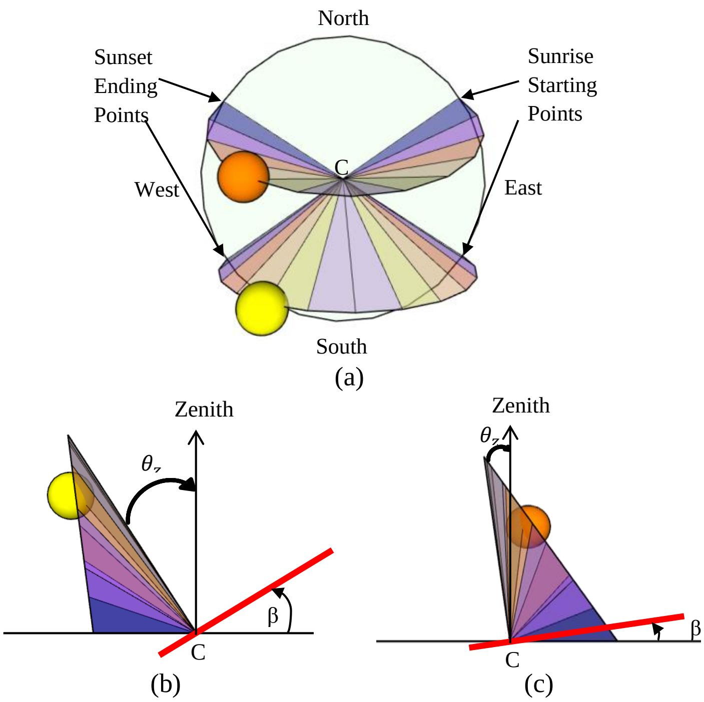

Figure 2. Sun path diagrams, (a) sun path -top view, (b) side view-sun path winter season, and (c) side view-sun path summer season

It is clear from the above diagrams that the sun position from the centre is changing. The angle between the sun and the vertical line is called Zenith angle θ_z [1], [2], [13]. The sun is almost vertical in the summer season, which means that θ_z is low and therefore the tilt angle β has to be quiet, around 10°. While in the winter season, the θ_z reads a higher degree, which means that β has increased to around 45°. The sun in other months between summer and winter seasons also has different Zenith angles, which means different β angles. The above diagrams also prove that the sun position is changing throughout the day. It was rising from the eastern horizon, making its way to the optimum tilt angle around midday, then falling to the west until it disappears with the horizon. The tilt angle can be calculated mathematically using (1) [1], [13].

$$\beta = |\emptyset - \delta| \tag{1}$$

where ∅ is the latitude angle that lies between a given point and the plane of the equator. While δ is the angle of declination between the solar radiation plane and the plane of the equator described in Figure 3.

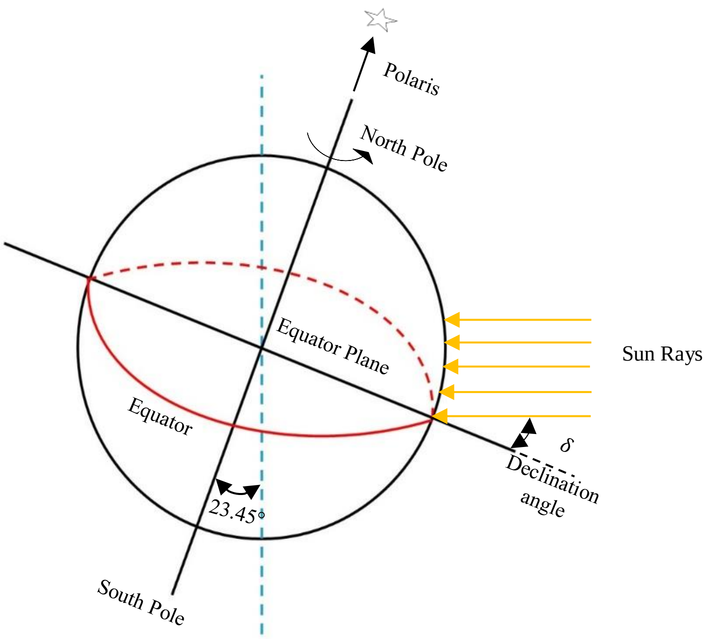

Figure 3. Declination angle

The latitude of Basra city is ($\emptyset = 30.50°$). δ can be calculated using (2).

$$\delta = 23.45 \times sin\left[360 \times \frac{(284+d)}{365}\right] \tag{2}$$

Where *d* is the targeted day of a year, starts from day 1, *d* = 1, if it is the 1st of January [1], [2], [13].

By using (1) and (2) an optimum tilt angle was calculated for each month. Table 3 shows how the sun tilt angle is changing throughout the year for Basra city. An optimum tilt angle is chosen after optimization to be the fixed tilt angle throughout the year for Basra city, $\beta = 28°$ [2]. This angle is selected to get the maximum output power from the PV system.

Table 3. Optimum tilt angles

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Tilt angle β	53°	45°	34°	22°	12°	7°	10°	17°	28°	40°	49°	54°

2.4. Power production and efficiency

Power production and efficiency have to be calculated and studded well to understand the difference between fixed tilt angle systems and sun-tracking systems. A 50 kilowatts peak (kWp) PV system was used as a model to do the power and efficiency calculations. To estimate the power production per day, a few factors need to be calculated first: the peak sun hours per day (PSH) and system derate factors [14]-[16].

As a fact, the peak sun hours per day (PSH) vary depending on which day of the year. PSH Basra city during the summer season is around 9.5 hours per day, while it is approximately 7 hours only in winter. [6], [12]. System derate factors (dc-to-ac derate factor) can be calculated by multiplying all the individual derate factors together, as presented in Table 4.

Table 4. Overall dc-to-ac derate factor calculations

Derating Factors	Derate Value	Range of Acceptable Values	
Nameplate Ratings	0.95	0.88-0.98	
Inverter and transformer	0.97	0.97-0.995	
Module mismatch	0.98	0.99-0.997	
Diodes and connections	0.97	0.97-0.99	
DC wiring	0.98	0.97-0.99	
AC wiring	0.99	0.98-0.993	
Soiling	0.98	0.30-0.995	
System downtime	0.98	0.00-0.995	
age	0.95	0.00-1.00	
sun tracking	0.98	0.00-1.00	
Shading	0.97	0.00-1.00	
Overall dc-to-ac derate factor	0.737	System Losses (%):	26%

The individual derate factors were carefully chosen according to the losses impact over system overall efficiency and compared to other similar studies [14]-[16].
Other factors including:

- Temperature losses, losses due to weather conditions at Basra city especially in summer, such heat has an effect over the production of power as explained earlier; Temperature losses $= 0.8$.
- Inverter efficiency, direct current-to-alternating current conversion (DC-AC) efficiency.

$$= \frac{\text{inverter's rated AC power output}}{\text{inverter's rated DC power output}} = 0.95$$

- DC to AC Size Ratio, is the ratio of the array's DC rated size to the inverter's AC rated size $= 1.2$.
- Ground coverage ratio (GCR), is the ratio between the surface area of the module to the base area which is occupied by that module $= 0.4$.

Two methods where adopted to obtain the daily production of power in KWh. The first method is a theoretical multiplication process. The second method is an online data analysis process. Two online calculators, which are the Global Solar Atlas [12] and PV Watts calculator [17].

3. RESULTS AND DISCUSSION

3.1. Power production

Table 5 shows the average daily PV production of power in kilowatt hour (kWh) calculated using:

Avg. daily PV production in kWh=PV array size in kW * Avg. peak sun hours per day * Temperature losses * Inverter efficiency * General system derate factor (3)

Table 5. Average daily PV production of power in kWh

Season	PV array size in kW	Avg. peak sun hours per day	Temperature losses	Inverter efficiency	General system derate factor	Avg. daily PV production in kWh
Summer	50 KWp	9.5	0.8	0.95	0.737	266,057 KWh
Winter	50 KWp	7	0.8	0.95	0.737	196,042 KWh

Table 6 shows a comparison between two solar systems producing power in kWh per month and the average amount of solar radiation. It is hard to decide which system is better for the customer without studying each system's advantages and disadvantages and comparing under different circumstances. If the tilt angle of the solar panel is fixed to a specific value, then the solar cells will not absorb the maximum amount of solar radiation, which was evident from Table 6. Therefore, a tracking system would be the solution here, as it will track the sun's movement from sunrise until sunset.

Solar tracking systems are classified as modern technology. Researchers have taken them into severe considerations because of their many features and advantages, including the ability to absorb more solar power from the sun during daylight hours. Therefore, their efficiency will be higher than the fixed systems. The annual production of such systems is higher by 15-30% than the fixed tilt angle systems [18], [19]. Their shapes look more modern, and some companies have turned them into something of unique architecture. For example, the solar power smart palms in Dubai and solar trees in America, Austria and Great Britain [20], [21]. Regardless of all the advantages of solar tracking systems, some disadvantages have to be mentioned. The cost of (O&M) of tracking systems is higher than that of fixed-tilt systems because they contain control systems, machines and moving parts used to move the axes while monitoring the sun.

Table 6. Solar radiation and power production

Month	System Size 50 KWp			
	Fixed system $\beta = 28°$		2-Axis Tracking system β = Auto (Tracking)	
	Solar Radiation ($kWh / m2 / day$)	Power (kWh)	Solar Radiation ($kWh / m2 / day$)	Power (kWh)
January	5.88	6107	7.52	7757
February	6.59	6188	7.84	7136
March	7.65	7688	7.94	7972
April	7.32	6900	8.16	7694
May	7.94	7409	9.16	8559
Jun	8.95	7890	10.07	8998
July	8.70	7967	9.71	9000
August	8.63	8091	9.39	8570
September	8.55	8010	9.25	8209
October	7.72	7254	9.15	8607
November	6.72	6030	7.56	6979
December	5.85	5983	6.26	6417
Annual	7.54 Average	85,517	8.50 Average	95,899

3.2. Weather factors and their effect upon solar system efficiency

Weather factors such as temperature, relative humidity, dust and wind, play a significant role in solar power production. Heat can reduce output efficiency by 10-25% [8], [14]. When the temperature of the solar panel increases, the output voltage decreases linearly, while the output current increases exponentially. As a result, heat can severely reduce the solar panel's production of power [8], [14]. As shown in Figure 4. The average temperature measures during daylight for the winter and summer seasons in Basra city are shown in Table 7.

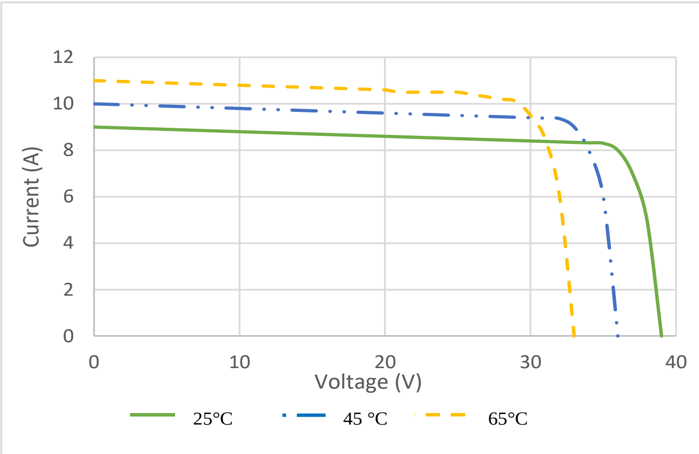

Figure 4. Temperature effects over current and voltage outputs

Table 7. Temperature variations during winter and summer seasons for Basra City

Season	Time	05:00	07:00	09:00	11:00	13:00	15:00	17:00	19:00
Winter	December	4°	5°	10°	15°	20°	18°	14°	11°
	January	4°	5°	11°	14°	18°	15°	13°	10°
Summer	July	31°	32°	38°	41°	47°	44°	40°	37°
	August	30°	31°	37°	42°	48°	45°	41°	38°

Relative humidity affects the performance of solar panels since it has a direct impact on solar irradiance [22], [23], [24]. The effect of humidity can be explained in this way: when solar energy reaches the ground, both the land and the surrounding air will absorb it. Therefore, the ambient temperature will rise.

If the humidity reads a high percent, the air absorption to heat is higher than the ground absorption [22], [23]. A worth to mention that the output energy from solar panel is only proportional to ground absorption [22], [23]. Therefore, if the ground absorption is low, it means that the output power is low. Figure 5 shows the effect of Relative humidity upon output power.

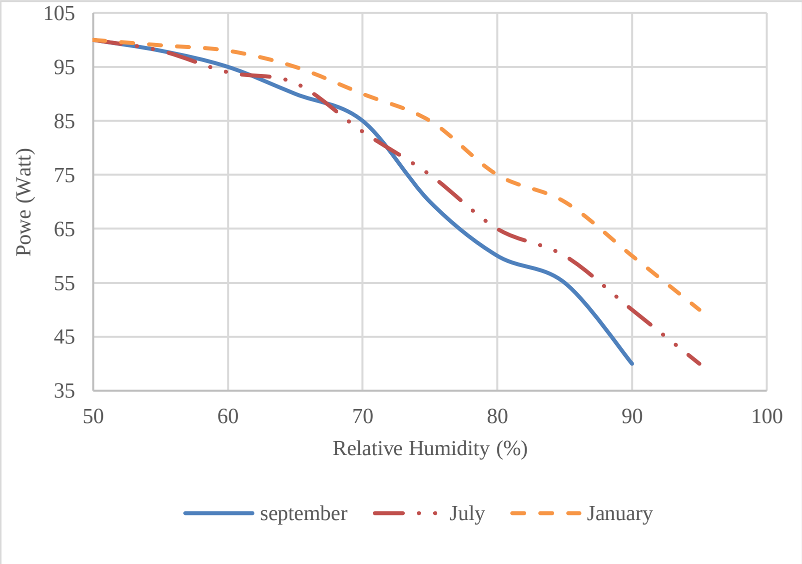

Figure 5. The effect of Relative humidity upon output power

Dust is another factor that has an impact on solar panel efficiency [14], [23]. Dust particles form an obstacle to solar radiation from reaching solar panels. There are two types of dust particles that form a dust shield over the surface of solar panels, which prevents the solar radiation from directly hitting the solar cells. Another type of dust particles floating in the air especially in the desert areas. These types of particles distort the solar radiations by deflecting, reflecting or absorbing the solar radiations.

The wind is considered as the natural solution to the previously mentioned weather factors. Wind can reduce temperature degrees by a considerable amount [24]. It also reduces relative humidity and removes dust from the surface of solar panels [7]. Nevertheless, the high wind speed can also be a problem of deformation of solar photovoltaic modules as different modules have different strengths and stress standards [25].

The mechanical structure of the solar system can change the effect of all the mentioned factors. The movable structure can reduce the amount of dusted particles collected over panels since movement (vibration) plays a force to displace dust particles from the surface of boards. Furthermore, movements help reduce the temperature of PV panels; the scene enables airflow `to hit PV panels from multiple directions during the day.

4. CONCLUSION

In conclusion, due to generation power shortages in the southern region of Iraq, and to overcome power demands, renewable energy has to be conducted instead of conventional power resources. This research is based upon different case studies dealing with other factors that influence solar energy production, such as geographical location, weather factors, tilt angles, sun path, solar angles, and solar radiations. Mathematical calculations based upon specific angles including latitude angle of Basra city, zenith angle and declination angle, were conducted to calculate the optimum tilt angle of each month for Basra city. Other theoretical calculations such as peak sun hours per day (PSH), system derate factors, temperature lossess and inverter efficiency were obtained to calculate power and efficieny of the proposed PV system. Global Solar Atlas and PV Watts Calculator were conducted in this study to find the difference in solar power production between fixed solar power systems and tracking systems at Basra governorate. The study concluded that the annual production of the tracking system is higher by 15-30% than the fixed tilt angle system. Adopting solar tracking systems in electricity production is highly recommended because they have more advantages than fixed solar systems in terms of power production and efficiency, and environmental aesthetics. In addition to overall advantages of reducing environment pollution and cost of production of electricity. Further work is being carried out regarding the investigation of home's energy efficiency supplied by solar systems under different load appliances for different seasons at Basra city.

ACKNOWLEDGEMENTS

We thank Mr. Ahmed Alnaab (Iraqi Ministry of Electricity, south control center) for providing us with the necessary data. This work was supported by Basra University for Oil and Gas, Basra, Iraq.

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BIOGRAPHIES OF AUTHORS

Ismaeil R. Alnaab Experienced lecturer with a demonstrated history of working in the electrical and electronic engineering industry. Skilled in Engineering, Project Planing, Project Management, and Product Development. Strong education professional with a master of science (MSc) focused in Electrical Power Engineering from Newcastle University, UK. Two years experience in the filed of IVMS (In Vehicle Monitoring System), worked as a subcontractor with BP, Baker Hughes, Weatherford, TAQA, SOC. More than two years experience in the field of QA/QC engineering at Southern Technical University. He currently working as a department rapporteur and assistant lecturer at the Department of Polymers and Petrochemicals Engineering at Basra University for Oil and Gas. He can be contacted at email: Ismaeil.r.alnaab@buog.edu.iq.

Harwan M. Taha received his M.Sc. degree in Electrical Power from Newcastle University, United Kingdom, in 2016, and his B.Sc. degree in Electrical and Computer Engineering from the University of Duhok, Iraq, in 2010. He is currently a lecturer and officer of the scientific affairs unit at Duhok Polytechnic University\Technical College of Engineering (TCE). His research interests include renewable energy, power electronics, and electrical machines. He can be contacted at email: harwan.taha@dpu.edu.krd.

Zainab A. Abdulwahab received her B.Sc. degree in Petrochimical Engineering from Basra Engineering Technical College, Iraq, in 2019. She is currently a process engineer at Basra Oil Company, Rumaila Operating Organization. Her research interests include petrochimcial engineering, polymers, process control and mass transfer. She can be contacted at email: zainabaltaha97@gmail.com.

Mohammed Salah Al-Radhi received a B.Sc. degree in Computer Engineering at Basra University in 2007, and a M.Sc. degree in Communication Systems Engineering at Portsmouth University, UK which was achieved with first-class honours in 2012 and awarded the MSc top student certificate in 2013. He received his Ph.D. from the Faculty of Electrical Engineering and Informatics at the Speech Technology and Smart Interactions Laboratory in Budapest University of Technology and Economics, Hungary in 2020, where he obtained it with honour (100%) and summa cum laude. Since October 2020, he was a postdoctoral researcher in the Department of Telecommunications and Media Informatics, BME, Budapest. He served as a reviewer for several top-tier journals and conferences proceedings. Currently, he served as an editorial-board member for the journal of Electronics. His main interests are Artificial Intelligence and Machine Learning in signal processing. He can be contacted at email: dr.malradhi@gmail.com.