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Assessment of the potentials of solar energy and radiation at the Islamic University of Medina

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ABSTRACT

The availability of radiation measurements is an essential factor in the evaluation of solar potential when a photovoltaic plant is to be installed. This paper addresses an assessment of the measurements and analysis of solar radiation in Medina, Saudi Arabia. The actual measurements are taken from a meteorological station located on the roof of the Engineering laboratory building at the Islamic University in Medina, KSA. The obtained results are satisfactory and prove the reliability of the constructed numerical models.

1. Introduction

The Kingdom of Saudi Arabia (KSA) is the most prominent country in the Middle East in terms of population, economy, and geographic outreach. Its rich oil and gas reserves, amongst the largest in the world, coupled with highly subsidized energy prices have contributed towards making Saudi society energy-intensive. Saudi Arabia is keen to reduce its dependence on the oil and gas-based energy sector by diversifying the supply mix. Renewable energy is an attractive option and the country has aimed to develop 9500 MW of renewable energy projects by 2023 (Nguyen and Kleissl, 2015; Pecenak et al., 2017; Tevar et al., 2019). Solar energy is the main renewable resource the country can tap and hence is projected to be the main contributor towards meeting the target set by the ruling body.

There have been a few solar energy initiatives in the country in the past, however, the focus has been on large-scale projects overlooking small-scale and building integrated applications. The use of PV systems in the building sector, especially in residential buildings, needs to be taken on board. The geographic location of Saudi Arabia is well placed for capitalizing on solar energy with the average daily solar radiation level reaching 6kWh/m2 and 80–90% of clear sky days over the year (Moghimi and Elahimanesh, 2017; Yuvaraja et al., 2016). The annual solar radiation may reach a level over 2400kWh/m^2 as shown in Fig. 1 (Emmanuel and Rayudu, 2017; Dubey and Santoso, 2016). Despite such a rich potential and having initiated a sizeable solar village electrification project as early as 1981, the country is yet to make a meaningful utilization of solar energy. Under the Vision 2030, however, solar energy is being planned to contribute most of the 9.5 GW renewable resources targeted with an increasing PV industry, the ability to offer elaborated expectations on power production over a system by the time, which become necessary for the human being. The efficiency competence with which sunlight is converted to power and how this relationship changes over time, are two key cost drivers for PV systems (Pompodakis et al., 2016; Navarro-Espinosa and Ochoa, 2015; Ruíz-Garzón et al., 2018; Lave et al., 2015). The degradation rate quantifies power decline over time. If the degradation rate is known, accurate predictions of the production can be made. Studies on these aspects will be of great importance to the Saudi Arabia PV industry (Argüello et al., 2017; Doğanşahin et al., 2018), and is what this paper aims to contribute to. With a growing PV industry, the ability to give precise predictions on power production over a system's lifetime becomes of vital importance.

2. Experimental site and instruments

The experiment site is the Islamic University (IUM) which is located in Medina, Saudi Arabia. As

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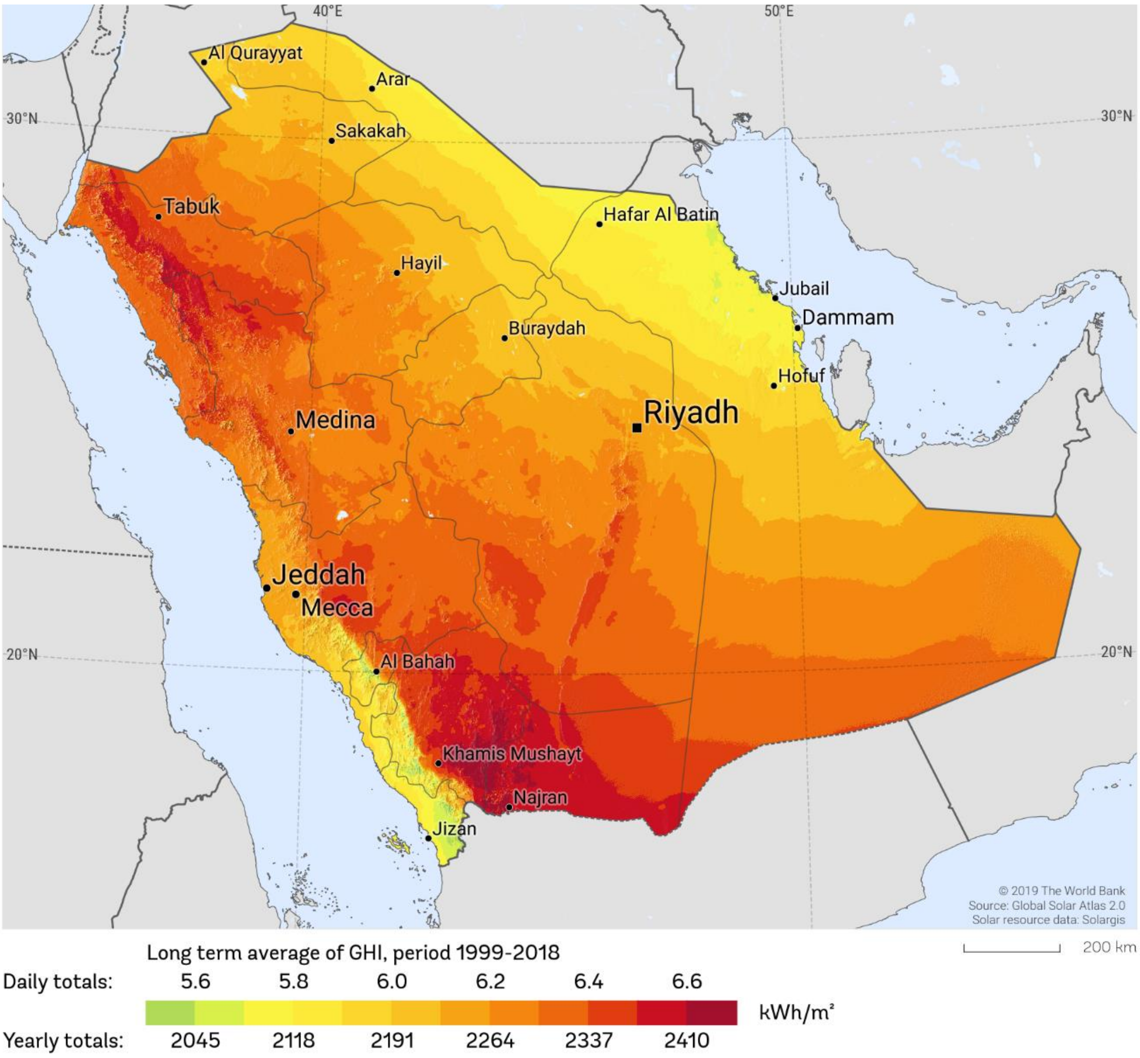
illustrated in Fig. 2, Saudi Arabia is part of the northern hemisphere located in Western Asia. It is divided into 13 administrative regions. Medina is the capital of the Middle region. It is situated 619 meters above sea level in the fertile mountains of western Saudi Arabia. Its coordinates are listed in Table 1.

The PV system is installed on a south-faced rooftop with a tilt angle of 6°, on the parking lots which is a part of IU campus as can be shown in Fig. 2.



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Source: Global Solar Atlas 2.0
Solar resource data: Solargis

Fig. 1: Global horizontal irradiation map of Saudi Arabia

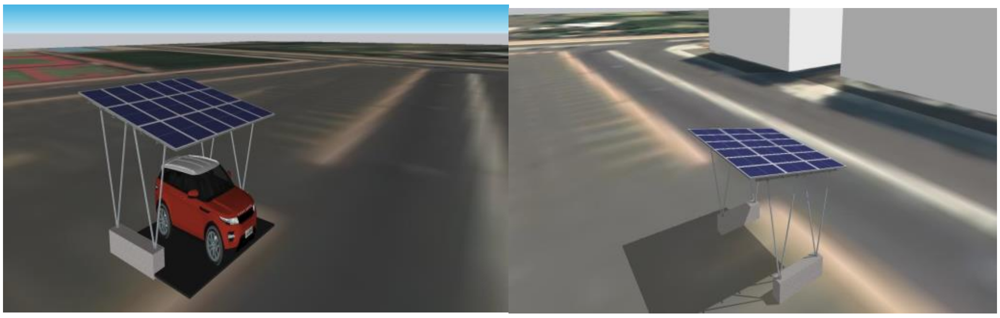

Fig. 2: Picture of the PV system at Islamic University at Madinah in Saudi Arabia

3. Geographical location and PV system parameters

The system is located far away from the marine environment and the weather conditions can be considered not so rough. The selected parameters for tilt and azimuth angle for the system are listed in Table 1. The parameters are selected with respect to the actual values of the existing system.

The prediction of the energy yield of a PV system varies from one modeling software to another, as well as, from one modeler to another. For this project PVsyst simulation software version 6.86 has been chosen. Presently, this is one of the most used simulation tools in the PV industry. With PVsyst, the estimated power generation of the solar power plant can be carried out for the geographical location under study. It uses irradiance and climate data from the Meteonorm 7.2 database and evaluates irradiance on a tilted plane and average ambient temperature. A meteo file for the specific time period is prepared as a *.csv file so that it can be imported to PVsyst as an ASCII file from Meteonorm 7.1 database.

Table 1: The geographical location of the PV system at Medina and the orientation parameters

Name	IUM Faculty Of Engineering
Location	Medina
Address	8183 Al Jamiah, 42351 2870
Latitude	24.48º
Longitude	39.56º
Maximum temperature	40.85 ºC
Minimum temperature	10.87 ºC
Global irradiation on a horizontal plane	2,208.25 kWh/m^2
Connection type	BT-Tri
Nominal voltage	400.00 V
Number of PV modules	90
Intercepting surface	180.0 m^2
Azimuth	-5°
Tilt	6°

The accuracy of simulations in PVsyst depends strongly on the input meteorological data and simulation parameters. The method for validating the model is to compare simulated results to measured data. The validation of a model comes down to two components: Measurement and modeling accuracy.

PVsyst is based on a one-diode-model with current-voltage (I-V) parameters adjustment as per specifications supplied by the manufacturer. PVsyst simulates the electrical behavior of the modules using manufacturer-provided specifications and measured data. Geographical location, tilt-angle and orientation, components details, and electrical configuration of the system are fed as inputs by the user. PVsyst software offers the approaches for comparing simulation results and actual results with a wide span of a time period of power generation. PVsyst has a 3D-scene capability, enabling the users to create an accurate 3D model of the PV system and its surroundings, which is then used for extensive calculation of the shade-induced losses.

In PVsyst several parameters and settings can be implemented to achieve an accurate model compared to the real system. To obtain simulation results close to the real measurements, we have to have a model which is very similar to the real system with respect to the design of the system, loss factors, and other parameters. Not all simulation parameters give a big impact on the result. By comparing the results before and after implementing the selected parameters, their impact and importance of them can be analyzed. In many cases, information about parameters is lacking, such that the knowledge of their importance of them in simulations can be of great interest. If some settings can be excluded because of their low impact on the output, this can make simulations easier in some cases.

This study is carried out for the model of the system at the College of Engineering which is located in Medina, Saudi Arabia. The results and conclusions can be used for simulations of other systems in different locations in KSA, similar to Medina. The results of interest for these simulations were total yield, performance ratio, and specific yield.

Fig. 3 shows the optimization of plane tilt and orientation implemented in PVsyst. The azimuth angle of -5° was found by using Google Earth and is an estimation of the actual azimuth angle of the PV array and building. South is 0° according to Fig. 3, which is the definition of the azimuth angles in PVsyst. A comparison of the selected parameters to the optimum is also provided, as seen in Fig. 3, loss by respect to optimum is -1.7% with the selected values. Some additional settings for the study include albedo settings and reference temperatures for the design of the PV array. Albedo coefficient is the fraction of global irradiation reflected by the ground to the tilted plane. The albedo value increases with tilt angle and is zero for an array with 0° as tilt angle. Albedo values can be set for each month, and NASA provides global albedo values. The overall albedo value for the model is though set to a default value of 0.2, which can be considered a reasonable value for Madinah when considering the surroundings.

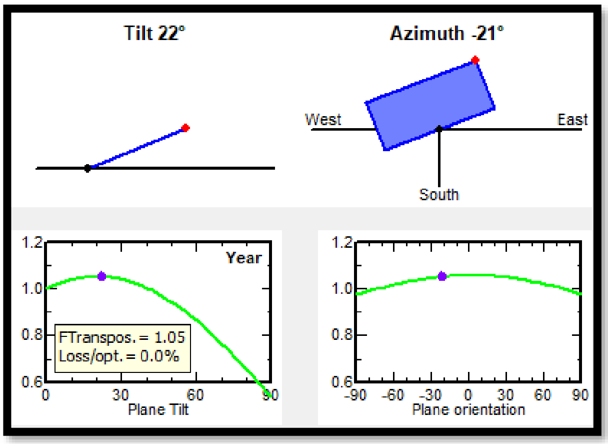

Fig. 3: Tilt and azimuth angle selection in PVsyst with comparison to the optimal angle

4. PV array and inverter

The PV system at the College of Engineering at Madinah consists of PV modules connected in series for the realization of the strings, electric cables for connection between modules and electrical panels. Whereas, the conversion group of the photovoltaic system will consist of one inverter for a total output of about 7.83 kW. Moreover, the photovoltaic generator consists of 2 strings of 9 modules connected in series, a group of interfaces, systems of measurement of energy. The PV array parameters considered here have the following manufacturer parameters shown in Table 2.

The nominal AC power of the inverter is 7.22kW and the maximum AC power is 7.8kVA as the name indicates. Maximum efficiency is 98.5% at a voltage level of 1080V. The maximum efficiency is set to be 98.5% according to European efficiency, which is the average operating efficiency over a yearly power distribution corresponding to middle-Europe climate. The efficiency curve of the inverter is shown in Fig. 4. The inverter has two MPPT inputs which make it possible to connect strings with a different number of panels to one inverter. The nominal power of the two strings connected to the inverter is 7.83Kw ac which fits well with the inverter's nominal power. The default setting in PVsyst is that the limit of the inverter power is set to nominal power. Also, Table 3 shows inverter parameters.

Table 2: PV array parameters and characteristics

Construction data of the modules	
Manufacturer	Canadian Solar Inc.
Model	CS-435W.p
Technology	a-Si:H single
Nominal power	435.00 W
Tolerance	1.23%
Open circuit voltage (V_{oc})	48.60 V
Voltage at maximum power (V_{mpp})	40.10 V
Short circuit current (I_{sc})	11.35 A
Current at maximum power (I_{mpp})	10.85 A
Area	2.21 m^2
Efficiency	19.7%

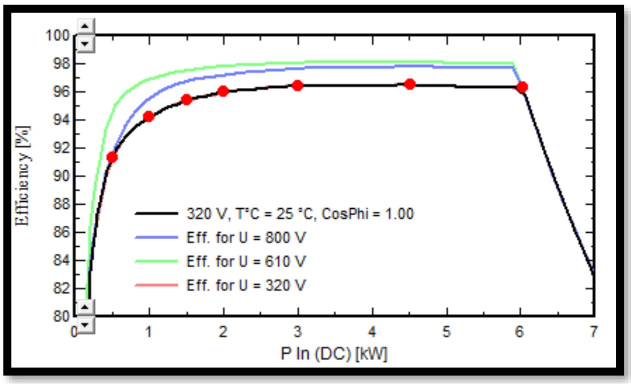

Fig. 4: The efficiency curve of the inverter

Table 3: Inverter parameters

Construction data of the modules	
Manufacturer	1. Fronius
Model	Symo 20.0-3-M
AC nominal output ($P_{ac,r}$)	20 kW
Max. output power ($P_{ac\ max}$)	20 kVA
Max. efficiency (PV - grid)	98,1 %
European efficiency (ηEU)	97,9 %
Number of MPP trackers	2
Max. input current ($I_{dc\ max}$)	33,0 / 27,0 A
Max. short circuit current, module array	49,5 / 40,5 A
DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$)	200 - 1000 V
Nominal input voltage ($U_{dc,r}$)	600 V
MPP voltage range ($U_{mpp\ min}$ - $U_{mpp\ max}$)	420 - 800 V
AC output current ($I_{ac\ nom}$)	28,9 A
AC voltage range (U_{min} - U_{max})	150 - 280 V
Output	Three-phase
Isolation transformer	False
Frequency (f_r)	50 / 60 Hz

For the system illustrated in Fig. 5, the following calculations can be made. The results of the simulations in PVsyst are generally represented in a report including simulation parameters, horizon definition, near shading definition, main results, and loss diagram. Fig. 6 shows a perspective of the PV field and surrounding shading scene. The Balances and main results are represented below in Table 4.

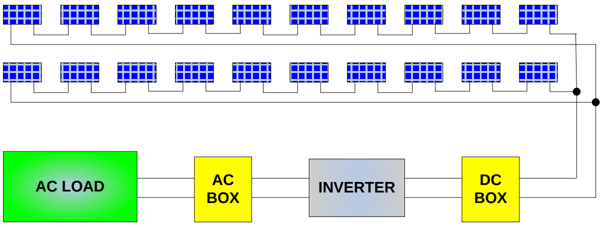

Fig. 5: Design of 4.8 kW PV system to supply a laboratory building

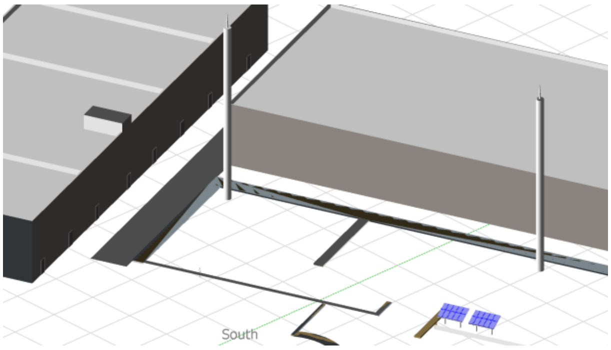

Fig. 6: Perspective of the PV-field and surrounding shading scene

Metronome was used as a database for meteo data for simulations for over a year. To get simulations with the actual meteo data, some selected dates were used.

5. Simulation results

In PVsyst several parameters and settings can be implemented to achieve an accurate model compared to the real system. To obtain simulation results close to the real measurements, the desire is to have a model which is very similar to the real system with respect to the design of the system, loss factors, and other parameters. Not all simulation parameters give a big impact on the result. By comparing the results before and after implementing selected parameters, their impact and importance of them can be analyzed. In many cases, information about parameters is lacking, such that the knowledge of their importance of them in simulations can be of great interest. If some settings can be excluded because of their low impact on the output, this can make simulations easier in some cases. This study is done for the model of the system at IU.

5.1. Power generated through the year

The earth cycle around the sun courses that the Change on the distance between the earth and the sun thus the distance is not constant through the year so deferent production each month is produced. We can see from the power generated through the year from the PVsyst simulation result (Fig. 3-8) that in October we get the highest monthly produce power and in Juley we get the lowest produce monthly power through the year, the reason is the tilt angle as the main factor and the irradiance and weather conditions as sub-factors. Note: On the following figures the production measured for each Kilo What (kW).

Fig. 7 shows the power generated through the year from the PVsyst simulation result.

Table 4: Balances and main results

Month	Diffuse daily [kWh/m^2]	Direct daily [kWh/m^2]	Global daily [kWh/m^2]
January	0.97	3.48	4.45
February	1.12	4.24	5.36
March	1.45	4.71	6.16
April	1.75	5.08	6.83
May	1.93	5.27	7.20
June	1.78	6.05	7.83
July	1.82	5.75	7.57
August	1.83	5.05	6.88
September	1.60	4.63	6.23
October	1.26	4.23	5.49
November	1.10	3.35	4.45
December	0.95	3.15	4.10
Yearly	532.90	1675.35	2208.25

Therefore, the energy produced by the system on an annual basis (Ep, y) is calculated as follows: $E_{p,y} = P_{nom} * I_{rr} * (1\text{-Losses})$ = 14,577.82 kWh, where: P_{nom} = Nominal power of system: 7.83 kW; I_{rr} = Annual irradiation on the surface of the modules: 2124.27 kWh/m^2; Losses = Power losses: 12.36 %

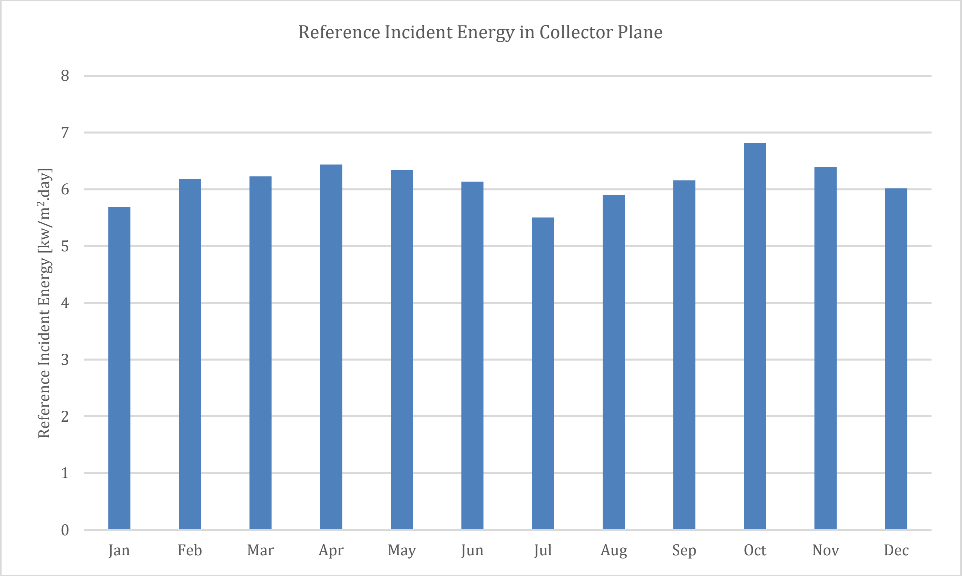

Fig. 7: Power generated through the year from PVsyst simulation result

5.2. Daily system output energy

In our simulation, we have taken into consideration the approximation of weather conditions according to meteo norm stations (Meteo databases). We can see the low production on some days through the year due to weather conditions approximation as shown in Fig. 8.

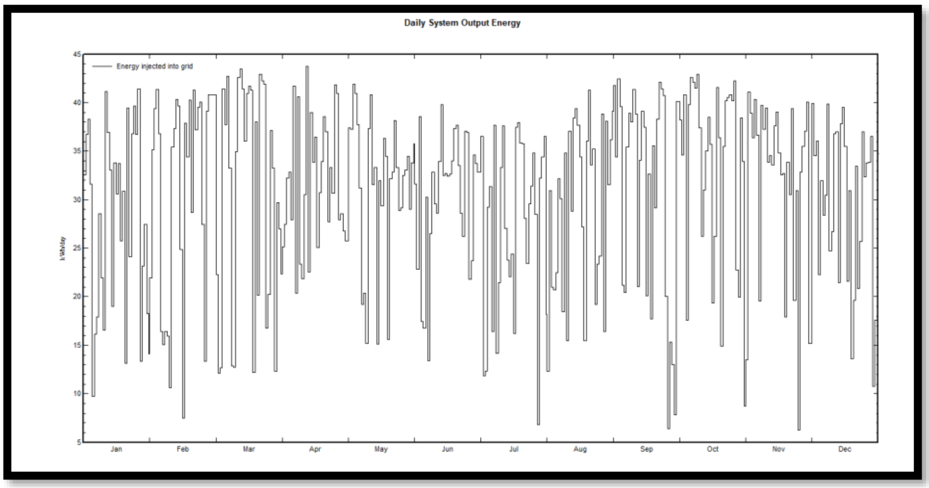

Fig. 8: Daily system output energy

5.3. Optimal tilt angle and azimuth on Madinah

We discussed the effect of the Tilt angle and the Azimuth on the production. As we can see the optimal Tilt angle is 6° and the optimal Azimuth is 0 as shown in Fig. 9.

But on our system, we used 6° as tilt angle due to the limitation of manufacture technologies to our structure supplier and -5° as azimuth due to the parking lots azimuth so we made the structure parallel to the parking lots.

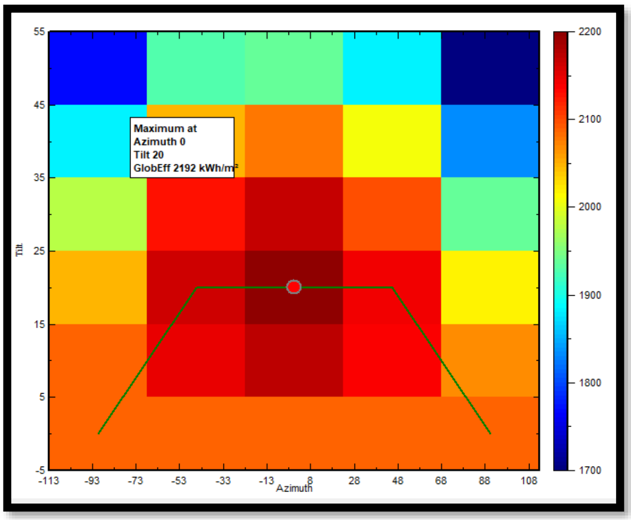

Fig. 9: Optimal tilt angle and azimuth on Madinah

6. Conclusion

This paper has successfully pinpointed the climatic and environmental issues that can affect the performance of solar PV technologies in Madinah. The effects of Irradiance, ambient temperature, and relative humidity on the power efficiency of polycrystalline silicon PVs have been deliberately studied. Experimental results showed that the effect of Irradiance was much greater than that of the relative humidity and ambient temperature. On the other hand, PVs were more affected with an increase in temperature and relative humidity above 29°C and 30%, respectively. Nonetheless, this does not eliminate the need to devise clear strategies for implementing cooling systems that can be powered by the PVs themselves, if reliable PV systems are sought. Also, Operating the PV panels from 11:00 am to 02:00 pm was found to give the maximum power on a daily basis. The outcome of this work helps to design high-performance PV plants and prevent costly damage and power breakage in hybrid systems under harsh environments. Future work will consider the automation of the measurement of panel efficiency due to the climatic and environmental factors over all seasons.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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