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A Performance Study of Fixed, Single-Axis and Dual-Axis Photovoltaic Systems in Kuwait

A. Al-Rashidi, A. El-Hamalawi

***Abstract*—**In this paper, a performance study was conducted to investigate single and dual-axis PV systems to generate electricity in five different sites in Kuwait. Relevant data were obtained by using two sources for validation purposes. A commercial software, PVsyst, was used to analyse the data, such as metrological data and other input parameters, and compute the performance parameters such as capacity factor (CF) and final yield (YF). The results indicated that single and dual-axis PV systems would be very beneficial to electricity generation in Kuwait as an alternative source to conventional power plants, especially with the increased demand over time. The ranges were also found to be competitive in comparison to leading countries using similar systems. A significant increase in CF and YF values around 24% and 28.8% was achieved related to the use of single and dual systems, respectively.

***Keywords*—**Single-axis and dual-axis photovoltaic systems, capacity factor, final yield, renewable energy, Kuwait.

I. Introduction

THERE is no doubt that a continuing increase in electricity demand is going to be problematic for the future of the world. A high demand of electricity will increase the use of conventional natural energy resources such as fossil fuels. As a result of this, greenhouse emissions (such as carbon dioxide) would increase, in turn increasing the complexity of environmental pollutants and global warming. Recently, there has been a worldwide move towards the use of renewable energy technologies to generate electricity as a substitute, or in conjunction with conventional power plants.

In Kuwait, it is generally believed that constructing new conventional power plants is an inappropriate way to deal with the increased demand in electricity, due to the large variation of electrical demand between summer and winter, which is estimated to be between 50% and 60% [1]. In addition, constructing new conventional electricity plants will create a huge strain on the national budget as well as environmental pollutants in the form of increasing CO_2 emissions. International community pressure, represented by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol, is another factor that needs to be taken into account.

Photovoltaic solar energy was chosen as a renewable energy to be implemented in this study because of the high potential for solar energy in Kuwait. Kuwait has an average daily sunshine of about nine hours and annual solar irradiation around 2100-2200 kW/m^2/year [2]. In addition, the significant price decline in system components and in particular the solar modules which represent around 60% of the total system cost, increases the chances of success for such projects. PV system performance is a key element in assessing the feasibility of solar energy projects. A lot of studies have examined the feasibility of using Photovoltaic systems in Kuwait and Gulf and the main findings of these studies are encouraging [2]-[6]. However, no studies have investigated the effects of using single and dual axis systems. In this paper, the effects of this will be examined at five different sites in Kuwait, and the results will be compared with fixed tracking systems. The results of this study will then be compared with some leading countries using these technologies such as Germany and Italy.

The tracking system is generally used to increase the annual solar radiation received and it is generally estimated that PV modules can gain more solar irradiation (30-40%) than fixed tilt mounting systems [7]. However, sun-tracking systems will require bigger and deeper footings because they are heavier than fixed tilt axis mounting systems [8].

A. Al-Rashid is currently a PhD student at Loughborough University, UK (e-mail: A. Alrashidi@lboro.ac.uk).
A. El-Hamalawi is an associate professor with the civil & building engineering school, Loughborough University, Loughborough LE11 3TU, UK (phone: +44-1509-223206; e-mail: A. El-Hamalawi@lboro.ac.uk).

II. Selected Sites and Metrological Data

The following sites in Kuwait, namely, Shagaya, Kabd, Sabria, Mutribah and Umm Gudair have been selected to implement this study and are shown in Fig. 1 on the Kuwait solar map. The location and elevation of the selected sites are listed in Table I. The selected sites were chosen as they represented the various geographical parts of Kuwait; Mutribah represents the northern part of the country, Umm Gudair, the southern part, Shagaya and Kabd, the western and eastern parts of Kuwait, respectively. In addition, Sabria site is the closest to the biggest Kuwaiti islands (Failaka and Bubiyan) and could be considered as the best representative site for them.

TABLE I
Selected Sites (Data Collected From the Kuwait Institute for Scientific Research (KISR)

Site Name	Latitude (N)	Longitude (E)	Elevation (m)
Shagaya	29.2^0	47.1^0	240
Kabd	29.2^0	47.7^0	76
Sabria	29.6^0	47.9^0	74
Mutribah	29.9^0	47.4^0	88
Umm Gudair	28.7^0	47.8^0	201

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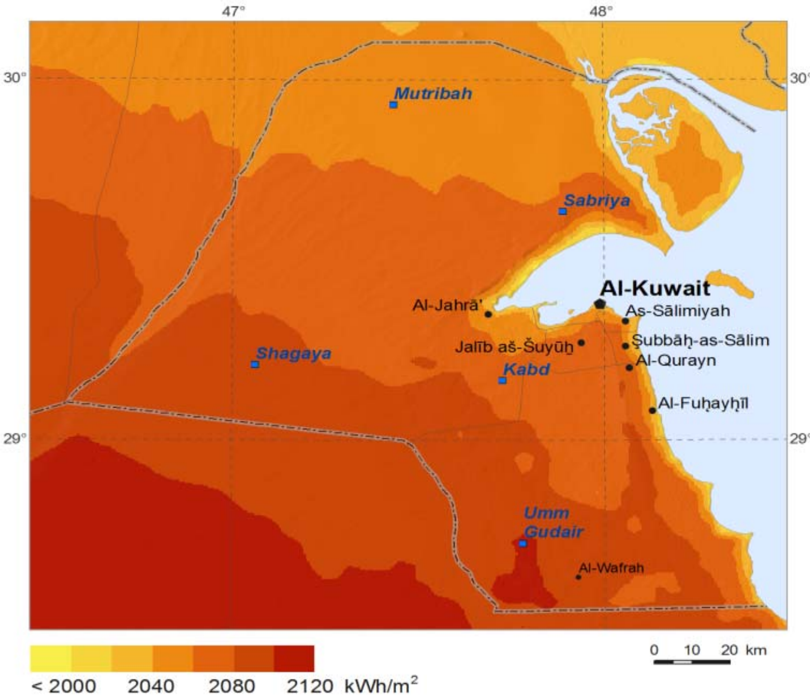

Fig. 1 Selected sites on the Kuwait solar map [9]

In order to determine the performance parameters of the Photovoltaic systems in the proposed sites, PVsyst software, a software package for the design and analysis of Photovoltaic systems, was used in this study. The key data inputs required to estimate the energy production from the proposed sites using this software are meteorological data (such as solar irradiance, temperature and wind speed), location, PV module type, inverter type, and the electrical and mechanical specifications of the used Photovoltaic modules. Inverters are required to perform the design and the analysis process of the proposed Photovoltaic systems. The meteorological data for the proposed sites were collected from KISR (Kuwait Institute for Scientific Research) and were used when assessing the sites by calculating the performance parameters. These data were derived from satellite data for all selected sites over a period from 1994 to 2012.

Ground station data for one complete year (September 2012 to August 2013) are also collected; each of the meteorological ground stations is based on a 10 m tower, consisting of four wind speed cup-type sensors at 1, 4, 6 and 8 m heights to derive the wind speed profile. In addition, a combined wind speed and direction sensor at 10 m height and one solar radiation sensor (pyranometer) with uncertainty of 5% (Fig. 2) were used.

The ground station data are used to validate the satellite data; the average annual solar radiation of the ground stations for Shagaya, Kabd, Sabriya, Mutribah, and Umm Gudair from September 2012 to August 2013 is shown in Table II. The satellite data and ground station data are almost similar and provide a very good indication of the quality of the collected data (Table III).

TABLE II
AVERAGE ANNUAL SOLAR RADIATION OF THE GROUND STATIONS FOR SHAGAYA, KABD, SABRIYA, MUTRIBAH, AND UMM GUDAIR FROM SEPTEMBER 2012 TO AUGUST 2013(DATA COLLECTED FROM KISR)

Site	Annual Solar (kWh/m^2/year)
Umm Ghdair	2176.8
Shagaya	2167.9
Kabd	2092.8
Sabreya	2086.0
Mutribah	2075.8

TABLE III
ANNUAL SOLAR (KWH/M /YEAR) FOR SATELLITE DATA AND GROUND STATION DATA FOR SHAGAYA, KABD, SABRIYA, MUTRIBAH AND UMM GUDAIR (DATA COLLECTED FROM KISR)

Site	Ground Stations	Satellite data	(Satellite/Ground) %
Umm Ghdair	2176.8	2123.4	97.55
Shagaya	2167.9	2054	94.75
Kabd	2092.8	2119.5	101.28
Sabreya	2086.0	2072.7	99.36
Mutribah	2075.8	2059	99.19

III. PROPOSED PV SYSTEM

A 100 MW grid-connected power station is proposed for all selected sites, where each power station is divided into 8 arrays with 12.5 MW for each array. A PV module type Si-poly model (S255P60 Professional) and Inverter type Sunny Central 630CP-JP Manufacture (SMA) were used in this study. The PV module specifications and the design configuration for each array are provided in Table IV.

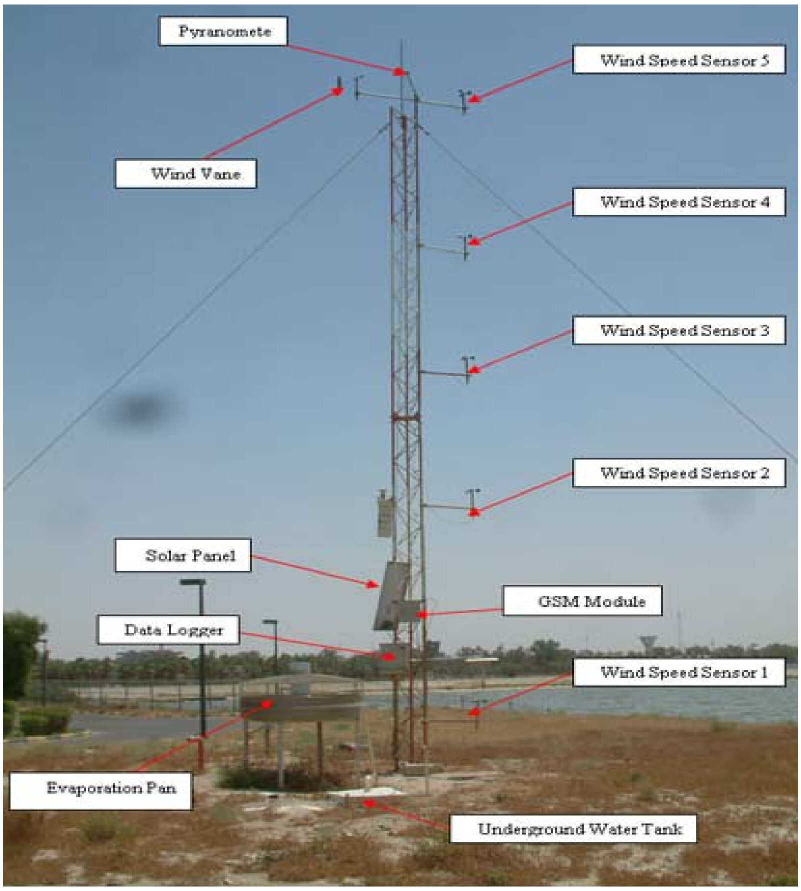

Fig. 2 A typical metrological station [9]

TABLE IV
DESIGN ARRAY CONFIGURATION AND PV MODULE SPECIFICATIONS [10], [11]

Total number of PV modules	49020 modules In series: 20 modules In parallel: 2451 strings
PV module type	Si-poly model (S255P60 Professional)
Maximum Power (P_{max})	255 W_p
Voltage at Maximum Power (V_{mpp})	29.87 V
Current at Maximum Power (I_{mpp})	8.54 A
Open Circuit Voltage (V_{oc})	37.69 V
Short Circuit Current (I_{sc})	8.99 A
Efficiency	15.50 %
Inverter Model	Sunny Central 630CP-JP Manufacture: SMA Solar Technology AG
Operating Voltage	500-850 V
Unit Nominal Power	630 kW
Number of inverters	19 units

IV. PERFORMANCE PARAMETERS

The International Energy Agency (IEA) stated that total energy generated by the PV system, YF, reference yield (YR), performance ratio (PR), CF and system efficiency are the main components of the performance parameters of photovoltaic systems [12].

TABLE V
PERFORMANCE PARAMETERS FOR THE SELECTED SITES

Site	**Annual Production** (MW/year)	**Yield factor (YF)** kWh/kWp/year	**CF** %
Shagaya			
Fixed	175075	1750.75	20.0
One axis Tracking System	217835	2178.35	24.9
Two axis Tracking System	225503	2255.03	25.7
Kabd			
Fixed	177519	1775.19	20.3
One axis Tracking System	218291	2182.91	24.9
Two axis Tracking System	225481	2254.81	25.7
Sabriya			
Fixed	175378	1753.78	20.0
One axis Tracking System	219772	2197.72	25.1
Two axis Tracking System	227556	2275.56	26.0
Mutribah			
Fixed	174347	1743.47	19.9
One axis Tracking System	218859	2188.59	25.0
Two axis Tracking System	226705	2267.05	25.9
UmmGudair			
Fixed	178843	1788.43	20.4
One axis Tracking System	223935	2239.35	25.6
Two axis Tracking System	231563	2315.63	26.4

YF, also called yield factor, is defined as the daily, monthly or yearly produced alternating current (AC) energy produced by the Photovoltaic (PV) system divided by the rated output power of the used PV system [12], given by:

$$YF = E_{AC} / P_{PV,\ rated} \tag{1}$$

The ratio of total solar irradiation (Ht) in (kWh/m^2) to the reference irradiation G (1 kW/m^2) is known as YR [12], [13], given by:

$$YR = (H_t)\ (kWh/m^2) / G\ (1\ kW/\ m^2) \tag{2}$$

PR is known as YF divided by YR, given as:

$$PR = YF / YR \tag{3}$$

CF is equal to the ratio of the annual energy output of PV system to the rated power of PV system [13], given as:

$$CF = E_{AC} / (P_{PV,\ rated} * 8760) \tag{4}$$

V. Results and Discussion

The detailed results of the performance parameters study for the proposed sites are provided in Table V.

The average annual production gained from using a fixed tracking system is 176232.4 MW/year while values of 219738.4 MW/year and 227361.6 MW/year could be gained by using single and dual-axis systems respectively. This increase in annual production, which is 24.7% and 29%, is a key element that should be taken in consideration in terms of feasibility assessment. It can be seen from Table V that CF for all sites for the fixed tracking system vary from 19.9% to 20.42%, while for single-axis and double-axis systems vary from 24.87% to 25.56% and from 25.74% to 26.43%, respectively. These values are within the typical CF range for PV systems (0.15-0.40) [4]. CF is a significant factor that should be considered when assessing the usage of a power source and its maximum value is theoretically equal to 100%. This value cannot be achieved practically because this needs an operation rate of 24 hours per day, which is impossible. For instance, if the sunlight is assumed to be available for 12 hours a day, the ideal CF value is going to be 50%. However, the maximum real CF is slightly lower than 50% and that is expected as a result of the energy conversion losses; the typical CF for PV systems varies from 15% to 40% [4].

YF values range between 1743.47 kWh/kWp/year and 1813.27 kWh/kWp/year for the fixed tracking systems. These results are excellent when compared with the leading countries using PV systems (Table VI).

A significant increase in CF and YF values around 24% and 28.8% was achieved with respect to single and dual systems respectively. The average values of PR for fixed, single and dual–axis systems are 77.5%, 76.4% and 76.2%, respectively. These values are important indicators for understanding the causes of the large amounts of lost energy as a result of solar energy conversion processes and the hot climate in the summer, which is an important characteristic of Kuwait.

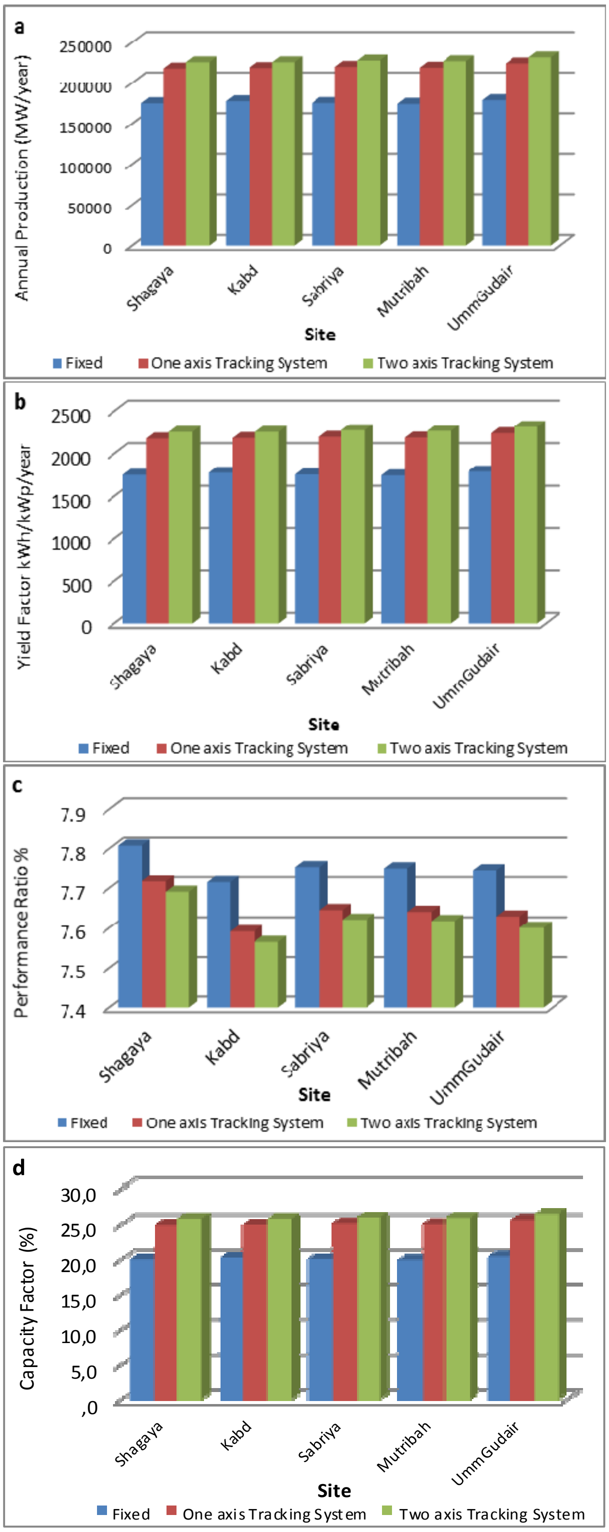

Fig. 3 Performance parameters for the selected sites: (a) Annual Production, (b) Yield Factor, (c) PR, (d) CF

TABLE VI
YIELD FACTORS (KWH/KWP/YEAR) FOR DIFFERENT COUNTRIES [4]

Germany	400-1300
Japan	470-1230
Netherlands	400-900
Italy	450-1250
Switzerland	450-1400

Fig. 3 shows a comparison between the selected sites based on the annual production, yield factor, PR and CF. It is clear that UmmGudair has the best results compared with the other sites, which is expected as the site has the highest annual solar irradiance. Moreover, it can be noted that although the Mutribah site has the lowest solar irradiance value (2075.8 kWh/m^2/year), it has same or slightly better results compared with Shagaya and Kabd sites which have better solar irradiance values. From this, it can be observed that analysing processes for all available metrological data are extremely important in order to get realistic results, especially in the "selection of sites" stage in solar energy projects.

VI. CONCLUSION

The average annual production gained from using single and dual-axis PV systems increased by 24.7% and 29%, respectively.

A significant increase in CF and YF values of 24% and 28.8% was achieved related to the use of single and dual systems, respectively. Although these are encouraging results, lower performance values were obtained for tracking systems, due to high energy loss resulting from overheating of PV modules due to the high temperatures in summer.

The performance parameters values obtained by using tracking systems and implementing single and dual-axis systems are very beneficial to the electricity generation in Kuwait as an alternative source to conventional power plants.

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