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On Seasonal Variation of Solar Irradiation in Kuwait

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Abstract-The technology for solar power generation is limited to numerous conditions that could affect the amount of energy received by the solar collector. In justifying the economic potential of solar energy at any geographical location the average data on solar irradiation is normally used. Nevertheless, it is not clear whether the use of average data is appropriate because irradiation could vary with seasons even in the desert. In the present work, the characteristics of solar radiation energy at a selected location in Kuwait were studied by measuring irradiance, using a pyranometer mounted on a shade-free area, throughout a year for comparison of extreme levels. The study revealed that the solar irradiation level was the lowest in winter and the highest in summer (three times the levels in winter), with an average monthly irradiation of 170.4 kWh/m². The variation in monthly irradiation was relatively high with standard deviation of 61.3 kWh/m². Consequent to this, there would be four months during which the irradiation would be far below the average value; i.e. lower than 120 kWh/m², and thus leading to requirement for backup power by mean of other source of energy.

Keywords-Solar energy, Solar collector, Irradiance, Seasonal variation.

1. Introduction

The demand for solar energy is increasing globally due to many reasons mainly associated to the growth in the world's population. The alarming environmental problems, the projected shortage in the supply of fossil fuel and also the escalating cost of energy are among the primary drivers that stimulate demand for solar energy. Renowned as a clean energy that has no direct release of emissions, solar energy is regarded as highly potential in addressing environment issues resulted from the combustion of fossil fuels, such as the greenhouse gas problem. Common solar energy conversion devices are the solar photovoltaic (PV) system for electrical power generation and solar thermal energy system for various purposed such as space and water heating, drying, and steam production. Solar PV systems convert the radiation energy from the sun into electricity through arrays of solar cells that are mounted on surfaces that are free from shade like open fields and roofs. At present, the solar cells technology is improving with the presence of variety of types for commercial solar cells, namely crystalline silicon cells, thin film, amorphous silicon, and multi-junction cells. Although expensive at the beginning, the cost of solar panels has dropped steadily in the last few decades. In December 2012 the price solar panels had dropped to $0.60/Wp [1], as compared to about $1.09/Wp in 2011 [2] and $100/Wp way back in 1971 [3]. Solar thermal energy, on the other hand, involves heating of fluids through collectors for applications ranging from domestic hot water system to electrical power generation (via steam turbines).

Despite the decreasing trend in cost, the present technologies to extract solar energy are still regarded as expensive. Naturally, solar power generation is bounded by the presence of sunlight and therefore the power is effectively available for only a few hours in a day, depending on the seasons. For electrical power generation, this would require backup power system such as batteries, which can be very costly. Even though expensive, solar energy has become widely applied. In 2008, the solar PV industry's combined global revenue alone was about US$37 billion [4].

The lifespan of solar PV cells can reach to only about 25 years, throughout which approximately six years will be taken to cover the energy consumed in its manufacturing processes [2]. As a result, any decrease in the efficiency of the solar power generation system throughout its life cycle is undesirable due to its high capital expenditure. A major factor that can lead to inefficiency of solar panels is reduction of irradiation, which can be caused natural obstructions such as dust or algae on the collector panels [3-4].

Variation of sunlight irradiation due to the sun's declination, which varies with the seasons, is another reason for reduction in light irradiation on solar panels. The nature of this problem may vary by geographical location. Because of the high capital cost of solar power generation systems, economic consideration is critical, and this involves estimation of the potential amount of power that can be generated, payback period, lifespan, etc., typically measured by average data. Hadi et al. [5], for example, suggested that the payback period for the usage of solar PV system would be at least seven years, although, in their calculations, a constant (average)value of annual solar insolation of 2,080 kWh/m²·yr was used—i.e., from the work of previous researchers [6-7]. The calculation could be different if factors such as solar insolation were taken into account.

The electricity tariff varies widely from country to country. Hence, installation of solar power generation systems may not be economical in some countries if the electricity tariff is lower than the cost (per kWh) of solar energy system. In some countries, the government provides incentives to promote usage of renewable energy systems through attractive schemes, usually with marginal profit. Therefore, any deficiency such as mistake in calculations or changes in surrounding environment (e.g. construction of tall building next to the solar panels) may lead to losses. The decisions for installation of solar power systems are usually made based on the average data on solar irradiation for a specific geographical location. However, it is often doubtful whether the use of average data is appropriate since solar power variability due to seasonal variation may affect actual performance of the collectors. The variation in solar irradiation caused by declination of the sun can lead to power production at below average. As a result, operators may need to rely on backup power systems more often than anticipated and this would consequently increase the operational costs.

Careful consideration must be made prior to deciding installation of solar power systems by making use of the data on local solar irradiation. Unfortunately, weather data can be expensive and difficult to obtain in some countries. Although there were reports on such studies, for instance in the work by Al-Enezi et al. [8] in Kuwait, they only estimated solar radiation through a readily developed model. Feasibility studies on solar heating using TRNSYS program such as those reported in the literature [9-11] were promising approach that could provide details on projected solar thermal power generation throughout a year. Such program, however, requires experience and can be costly. Direct TRNSYS simulation of electrical power generation from solar PV panel is impossible, although an attempt was made quite recently [12]. In this work, the solar energy at a selected site in Kuwait was characterized by measuring irradiance throughout a year, which comprised two different extreme seasons. The findings from this work would be useful in designing a reliable solar-based electrical or thermal power system in response to fluctuations in the solar energy received throughout a year.

2. Instrumentation

The albedometer (Delta-T Devices Ltd), comprised two high quality dome solarimeter (pyranometer) sensors (GS2-10), which were mounted back-to-back and were based on a thermopile detector, as shown in Fig. 1. The pyranometer covered spectral range of 0.3 to 2.8 μm for the measurement of direct and reflected solar radiation from the surface of earth with a sensitivity of 16.12 μV/Wm-² at normal incidence of solar flux. It could operate under a temperature range of between -40°C and 80°C. The pyranometer was supplied with a 10-m long cable with bare wire tails for connection to a data logger and a 1-m mast mounting pole with a bubble level. The pyranometer calibration was based on a side-by-side comparison with a reference pyranometer under an artificial sun. The reference pyranometer was compared with sun and sky radiation as source under mainly clear sky conditions using the "continuous sun-and-shade method." The measurements were performed in Davos, Switzerland (latitude: 46.8143°, longitude: -9.8458°, altitude: 1588 m above sea level). The combined uncertainty of the results of the calibration was ±3.5% based on the positive "root sum square" of three uncertainties. First, the expanded uncertainty of 3.4% due to random effects and instrumental errors during the calibration of the reference pyranometer. Second, the uncertainty in the correction for the systematic effect of a directional error (cosine error) during the calibration in Davos, estimated at ±0.5%. Third the expanded uncertainty of the transfer procedure (calibration by comparison), estimated at ±0.5%.

Fig. 1. The GS2-10 albedometer

3. Methodology

The albedometer was installed in a farm in Al-Abdali area located in the North of Kuwait in (latitude: 30° 1" E, longitude: 47° 71" E, altitude: 23 m above sea level), as shown in Fig. 2 (a). The area had about 10 hours of sunlight during the winter and 14 hours in the summer. The albedometer was connected to a data logger for data downloading and manipulation, as shown in Fig. 2(b). The pyranometer was cleaned daily to ensure that its cover was free from light obstruction particles like sand and dust. Measurement commenced on 1 January 2009 for one year. The radiation data were measured every five minutes and then averaged for 1-hour intervals throughout the study period.

(a)

(b)

Fig. 2. (a) The Albedometer installed in a farm in Al-Abdali area north of Kuwait and (b) the data logger that was connected to the Albedometer

4. Results and Discussions

The measurement data obtained covered hourly irradiance for 365 days in 2009. Fig. 3 shows a typical hourly variation of irradiance throughout the day on 1 July 2009. As shown in the figure, solar irradiance was measureable as early as 4.00 am during sunrise, which occurred early in summer time. The measured irradiation increased by about 240 kW/m² at every hour. The peak irradiation, of 1171 kW/m², was reached at 10.00 am. After 12 noon, the irradiation decreased at a rate of about 250 kW/m² per hour. The irradiation diminished after sunset at about 5.00 pm. In general, there was about continuous 7 hours of irradiation that exceeded 800 kW/m² on that day, which could be regarded as high. Albedo, which is the ratio of surface reflection to solar incidence, could be determined from the measurement system. It was reported in an earlier work [13] that the value of albedo in Kuwait was around 0.2. Details on albedo is not discussed further since it is beyond the interest of this work.

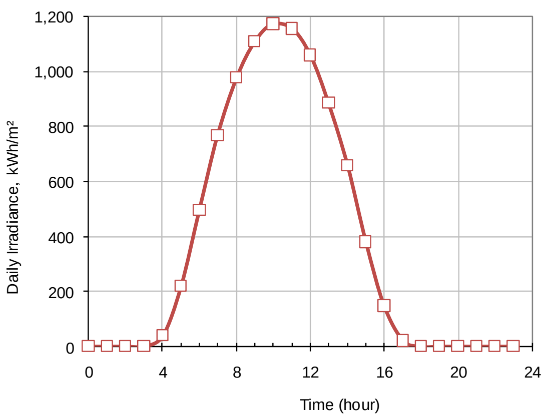

Fig. 3. Typical hourly variation of irradiation throughout the day on 1 July 2009

Shown in Fig. 4 are daily variations of accumulated solar irradiance (24 hours) from January to December. In general, it is shown that the irradiation varies throughout the year ranging between 2,487 and 29,374 kWh/m². Significant fluctuations in the irradiation are shown for February to April. The most extreme fluctuations occurred in the second week of June and in mid-April, which saw a drop by 22,694 kWh/m² and 20,901 kWh/m², respectively. It was probable that such high fluctuations were caused by sand storm as suggested by a meteorological report [14]. The irradiation was exceptionally high in June to August, most probably due to summer season, during which the solar irradiation was expected to be the most intense as a result of shorter distance between the sun and the site at that time.

Fig. 4 shows the daily variation of solar irradiation throughout the year without monthly segregation for better understanding of the annual trend. Also shown in the figure is the best fitted curve to represent the collected data. In general, the data is widely scattered especially in the season of spring. In the fall season, the scatter is shown to be minimum. As suggested earlier for Fig. 3, the scattering was probably influenced by sand storm. It is clearly displayed in Fig. 4 that the highest irradiance occurred in the summer, during which the distance between the site of study and the sun was likely to be the shortest. It is interesting to note that the difference of irradiation between the summer and winter seasons is about three times. Consequently, this would significantly affect the performance of solar PV and solar thermal collectors operated within the area of study.

Shown in Figs. 6 to 9 are hourly variation of irradiation throughout January, April, July and October 2009, respectively. In these figures, the hourly variations throughout a day are superimposed and thus the fluctuations throughout these months are displayed. Also shown in the figures are the best fitted curve (continuous line) by 5th polynomial fitting, and the curve for average results (dashed line). Basically the two curves are almost identical.

Overall, the hourly irradiations seem consistent except occasional deviation which may be due to the presence of light obstructions such as sand storm and haze. Similar to that explained for Fig. 2, the greatest fluctuation in irradiation is shown to occur significantly in the month of April. There were times when the measured irradiation were close to zero at 8.00 am when normally it was supposed to be high around 700 W/m². In addition, in April there is no specific time of the day that can be regarded as calm with consistent irradiation. The least fluctuations in irradiation among the four months occurred in July; i.e. around end of summer. The results shown in Figs. 4 to 9 implies that the solar energy fluctuated significantly and thus the power generated by the solar collectors would also fluctuate. This would lead to the need to prepare for additional power from other sources in order to make up the deficiencies, and therefore incurring higher operational costs.

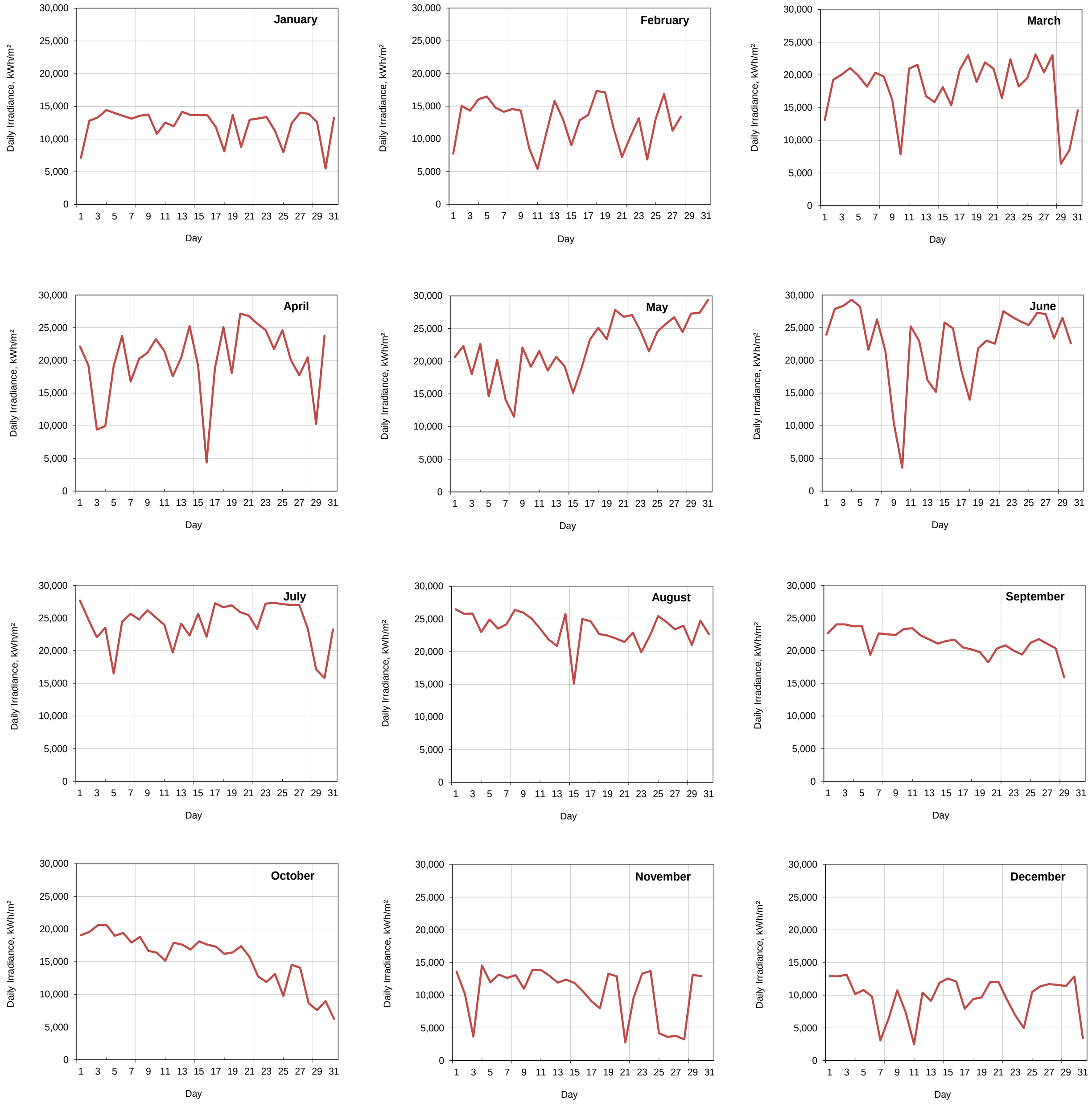

Fig. 4. Daily variation of accumulated solar irradiation from January to December

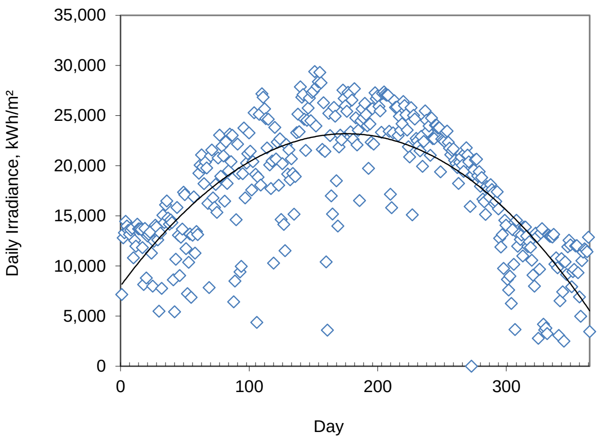

Fig. 5. Daily variation of daily solar irradiation throughout the year

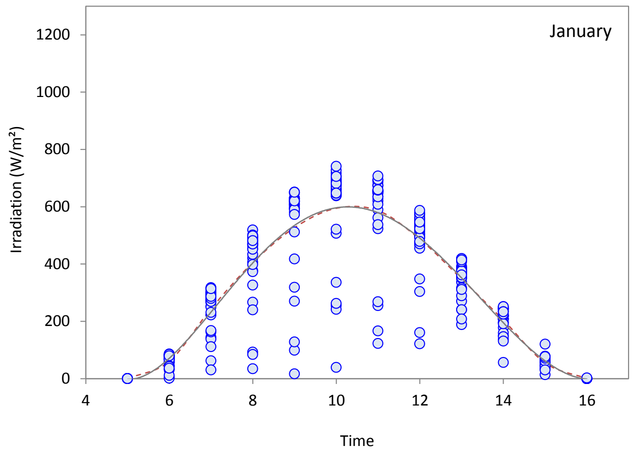

Fig. 6. Hourly variation of irradiation for January 2009

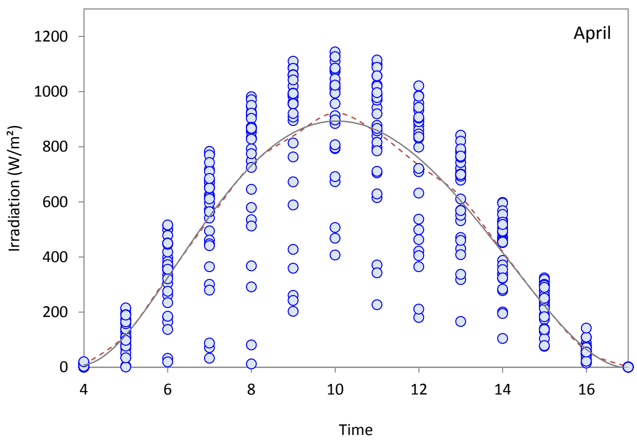

Fig. 7. Hourly variation of irradiation for April 2009

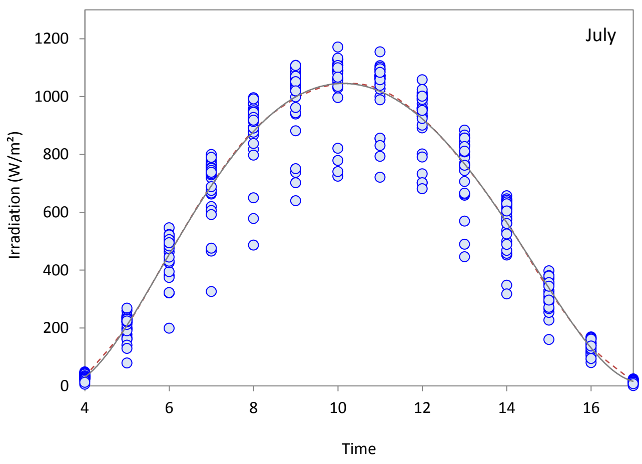

Fig. 8. Hourly variation of irradiation for July 2009

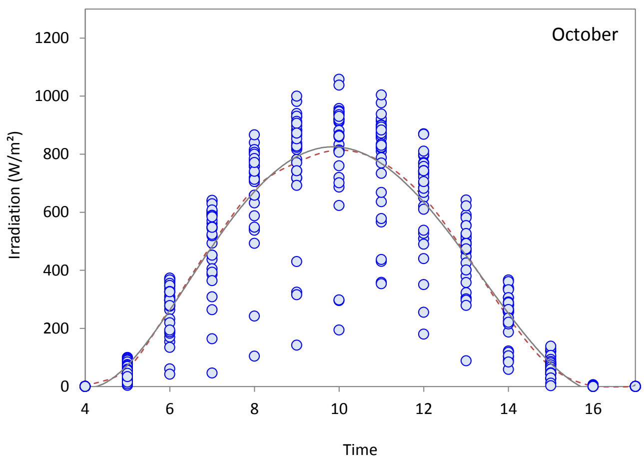

Fig. 9. Hourly variation of irradiation for October 2009

Shown in Fig. 10 is comparison of the average hourly variations of irradiation for January, April, July and October. It is clearly shown that the highest irradiation occurred in July (summer) and the lowest being in January (winter). In April and October, the amounts of irradiation are shown to be identical. However, the level is slightly higher in April despite the large fluctuations, as elaborated for Figs. 6 and 9, suggested to be caused by sand storm. Noting that the amount of energy received through sun irradiation is the area under the curve, it is clear from Fig. 10 that the most energy available is in the summer and vice versa during the winter. This is more precisely shown in Fig. 11, which displays histogram of distribution of monthly irradiation energy throughout the year. Generally the highest amount of solar energy received happened in the summer, with July as the peak month. It is interesting to note that the distribution in Fig. 11 is not symmetrical, for which greater amount of irradiation is displayed during the first half of the year as compared to the second half.

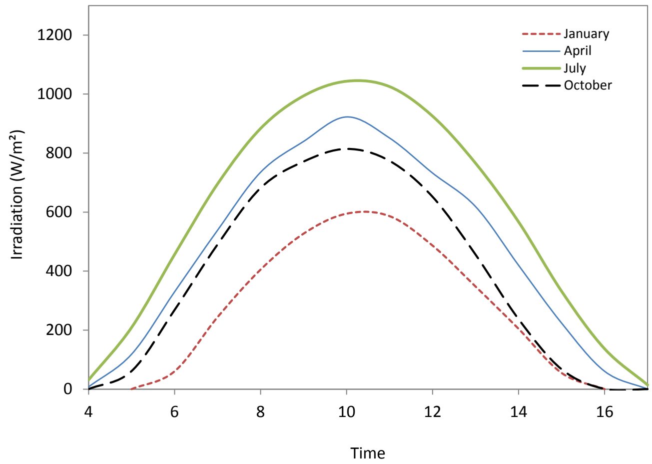

Fig. 10. Comparison of average hourly variations of irradiation for January, April, July and October

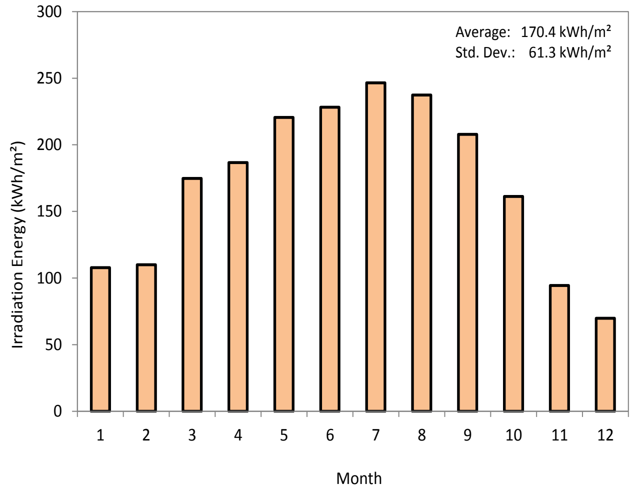

Fig. 11. Distribution of monthly irradiation energy throughout the year

The average monthly irradiation energy is shown in Fig. 11 to be 170.4 kWh/m². The standard deviation is 61.3 kWh/m² (36.0%), which is very large and in agreement with the findings presented in an earlier work [13]. The histogram in Fig. 11 supports the suggestion that solar irradiation in Kuwait is reduced quite significantly during winter and would therefore affect the performance of power generation (both electricity and thermal power). Due to large fluctuations, the amount of solar energy that can be harvested in the winter is less than that in the summer. Consequently, the backup power system would be required during winter to make up for the deficiencies.

5. Conclusions

A study was conducted to investigatethe trends of solar irradiance in Kuwait throughout a year. The following conclusions could be drawn from the study:

1. The day-to-day variation of irradiance in the season of spring was found to be high. This was suggested to be due to sand storm activities as reported by the meteorology office. On the other hand, the variation was small in the season of autumn (fall).
2. The highest irradiation occurred during the summer. As expected, the lowest irradiation occurred during the winter. The difference between irradiations in summer and winter was about three times.
3. The average monthly irradiation energy is 170.4 kWh/m² and the standard deviation was relatively high at 61.3 kWh/m², implying that there would be months during which the irradiation would be far below the average value.Consequently, if a solar harvesting system is designed based on the average value, there will be shortage of power supply from January to March and from October to December. As a result, a backup power system would be required in order to make up for the electrical power load demand.

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