Performance and Cost Assessment of Three Different Crystalline Silicon PV Modules in Kuwait Environments

A. Aldihani*‡, S. Mahmoud *, R.K. AL-Dadah *, A. Al-Qattan **

* Department of Mechanical Engineering, University of Birmingham, Birmingham, UK, B15 2TT

**The energy and building research centre, Kuwait Institute for Scientific Research, Kuwait, 1309

(AXA@student.bham.ac.uk, S.M.MAHMOUD@bham.ac.uk, R.K.AL-DADAH@bham.ac.uk, aqattan@kisr.edu.kw)

‡ A .Aldihani, Department of Mechanical Engineering, University of Birmingham, Birmingham, UK, B15 2TT, Tel: (+44)75 123 35777 , AXA178@student.bham.ac.uk

Received: 05.09.2016 Accepted: 15.12.2016

Abstract- paper experimentally investigates the performance of three photovoltaic modules (Monocrystalline back contact SP, Heterojunction HIT, and Polycrystalline Poly) in the Kuwait harsh climate conditions and their cost effectiveness. Dust particles from coastal and desert sites were optically characterised and results showed that for the same grain size (60, 80 and 100 microns) both the reflectivity and transmissivity were similar for both sites. As for the PV modules performance the effects of temperature which reaches 65oC on a July day and the dust accumulation over a period of 12 months were measured. Results show that the SP module is the most affected module by the dust with a drop of 53W while the poly is the least affected by the dust with a drop of 21W in the maximum power output. As for the cost effectiveness of these modules results showed that the poly PV module is more suited for the harsh Kuwaiti environment where the cost of 1 W is £1.89 for the poly compared to £2.13 for the SP and £2.21 for the HIT.

Keywords PV, Dust, PV efficiency, crystalline silicon, solar.

1. Introduction

Recently, there has been significant interest in solar energy as a renewable energy source to reduce reliance on fossil fuel and reduce carbon emissions. Kuwait enjoys high level of solar radiation, more than 7.7 kWh/m2/day [1], thus the utilise of solar energy became a priority in the Kuwaiti government strategy aiming to decrease the oil consumption and improve the environment [2]. However, Kuwait suffers from dust and sand storms as a result of its very little vegetation, dryness, weightless-textured surface soil and frequent unstable strong air currents [3]. In many applications, the electrical conversion efficiency of solar PV modules varies from 10-16% [4]. Nevertheless, the efficiency of outdoor set-up PV modules is generally reduced by 10 - 25% due to failures in the wiring, inverters and harsh environmental conditions [5]. Many investigations in Kuwait and neighbouring region were conducted to examine the effects of climate factors on the photovoltaic modules performance.

Wakim [6] measured a 17% drop in PV monocrystalline modules power output after one week period due to dust accumulation caused by the severe sand storm in Kuwait. Hasan et al. [7] measured the rate of dust accumulation in Kuwait between April and June around 2.5 g/m²/day, it was found that after 1, 13, 30 days drop in power output of 2%, 14% and 30%, respectively. Qasem et al. [8] examined the impact of dust after one month on Cadmium telluride photovoltaic module to correlate lights spectrum transmittance with dust deposition rate using glass samples covered with dust from Kuwait. Their results indicated for dust deposition rate of 8.5 mg/cm2, a spectral photocurrent reduction of 28.5%, 28.6% and 33% were measured for crystalline silicon (monocrystalline and polycrystalline), copper and indium gallium diselenide (CIGS) and amorphous silicon PV modules respectively. Another study in Kuwait by Al-Hasan and Ghoneim [9] measured instantaneously the IV characteristics of clean and dusty modules made of polycrystalline cells mounted for several months. It has been observed that with 1 g/m2 dust concentration on the module cover glass the short-circuit current dropped by 40% and the maximum output power was reduced by 34%. Sayigh et al. [10] explored the impact of airborne settled dust on sloped glass coats situated in Kuwait and observed a decline in glass transmissivity varying at 17 to 64% for slope directions varying from 0° to 60° correspondingly, over exposure period of 38 days.

Other investigations which were conducted in the neighbouring counties with similar climate to Kuwait, Adinoyi et al. [11] measured a 50% decrease in PV monocrystalline cells module peak power results after six months outdoor testing in Dhahran Saudi Arabia. Salim et al. [12] studied the effect of dust on power output from an array of fixed circular silicon PV cells in northern Saudi Arabia over 8 months period and observed 32% decrease in the monthly power output due to sand accumulation with 2.78% drop in PV modules current output per day. Nimmo and Saed [13] studied the effect of dust on a solar system made of one PV module and two solar collectors fitted outdoor in Saudi Arabia for six months. They measured 40% decrease in the efficiency of the PV module and 26% decrease in solar collector efficiency.

In Riyadh city, Saudi Arabia, El-Shobokshy and Hussein [14] observed that dust deposition layer significantly reduces the silicon PV array performance and highlighted that the dust physical properties need to be assessed and compared to the studied impacts. The investigation revealed that with dust layer thickness of 80 microns and solar radiation of 700W/m2 results in decreasing the energy yield from the PV array to around 80% of its original performance. El-Shobokshy et al. [15] investigated the effects of dust properties and deposition thickness on the performance of two concentrators made of six silicon PV cells with an area of 20×20 mm2 in Riyadh city, Saudi Arabia. The concentrators are. Their findings showed that dust particles less than 85 micron have greater influence on PV cells performance than the period of exposure.

Touti et al. [16] reported 10% reduction in efficiency of monocrystalline PV modules tested outdoor after 100 days of dust deposition in Qatar. Alnaser et al. [17] investigated the effect of dust accumulation on 500 kW PV array mixture of polycrystalline and monocrystalline cells in Bahrain. Their results showed power reduction of 60% due to dust accumulation on the PV array. Uncleaning PV Array for seven month produces natural dust layer with density starting from 5 to 12 g/m2, which cause the peak power to drop by up 40%. Al Hanai et al. [18] studied the performance of PV array system consisting of 21 thin-film PV modules at a tilted angle of 25° facing south in Abu Dhabi, UAE showing a decrease in PV array system efficiency near a 5.70% over 35 days. Ibrahim et al. [19] studied the effect of dust on the performance of 1700 kWh/kWp PV array including Monocrystalline, Polycrystalline and Thin Film panels for over six months in Cairo, Egypt. They measured a reduction in the energy yield of 25%. In Egypt, Hassan et al. [20] investigated the accumulation of aerial dust on PV module consisting of silicon cells showing that a 33.5–65.8% fall in PV module power output, when PV module are exposed for 1-6 months in outdoor testing condition respectively. In Iraq north Al-Alawy [21] concluded from 9 years period of study of dust glazing on glass horizontal surface that higher dust rate accumulation results in a 50% decrease in energy or more in the daily solar radiation. Boykiw [22] studied the effect of dust on monocrystalline PV modules for seven days outdoor exposure in Palestine and concluded that 5-6% degradation in efficiency.

Pavan et al. [23] studied the effect of dust on 1 MW polycrystalline silicon PV system during June to October period in Italy and measured a 6.9% power reduction. Sanusi [24] studied the effect of daily accumulation of dust layer on the amorphous silicon PV modules system, the efficiency of the clean PV system was improved than the unclean PV system near 20% during two years of hazy periods in Nigeria.

It is clear from the above that dust accumulation has a major impact on the efficiency or power output which varies from one geographical location to another. In this work, the effect of dust and temperature on the performance in terms of power output and efficiency of three commercially available crystalline silicon PV modules over a period of 12 months in the Kuwaiti environment in terms of dust and temperature. The first PV module (SP) is monocrystalline cells with all electrical connections located on the back of the PV cells to reduce resistive losses. The second module (HIT) is monocrystalline silicon layer bonded with layers of ultra-thin amorphous silicon. The third module (Poly) is polycrystalline module with large PV cells connected in series.

2. Kuwait Environment

During July and August, the average of daily maximum temperature is 48 °C while the maximum temperature reported in Kuwait was 53.9 °C at the desert area in July 2013 which is considered as a top reported temperatures in Middle East and the third top one worldwide [25]. Figure 1 illustrates the average maximum and minimum ambient temperature in Kuwait for year 2013.

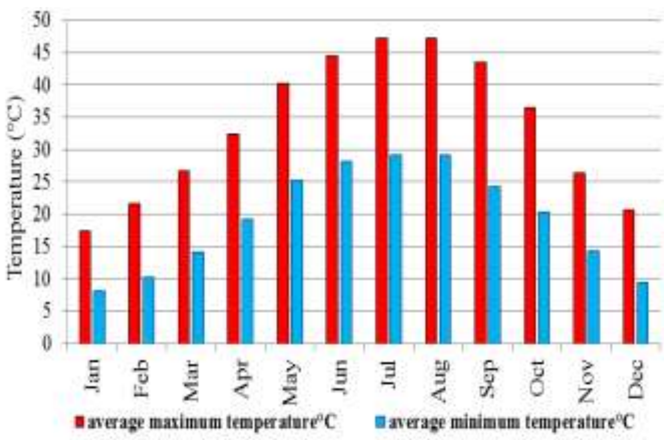


Fig. 1. The average maximum and minimum ambient temperature in Kuwait year 2013 [25].

The average daily hours of sunlight in Kuwait recorded by Environment Public Authority of Kuwait presented in figure 2. The month of July is the sunniest, while the month of December has the shortest time of sunlight hours.

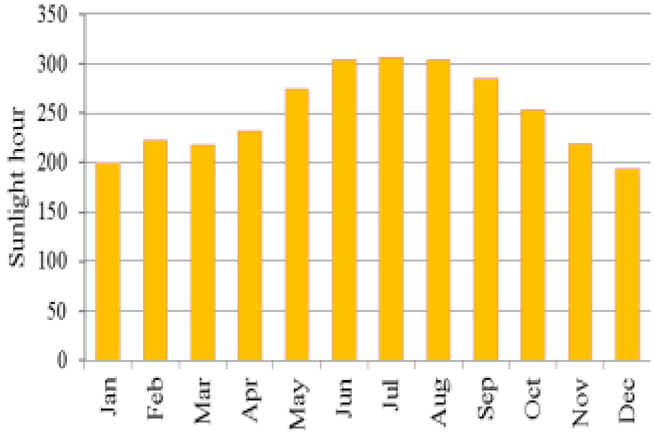


Fig. 2. The average daily sunlight hours in year 2013 [26].

The global hemispherical solar radiation data ($\overline{H}$) on horizontal plane was obtained from the Environment Public Authority of Kuwait as shown in Figure 3.

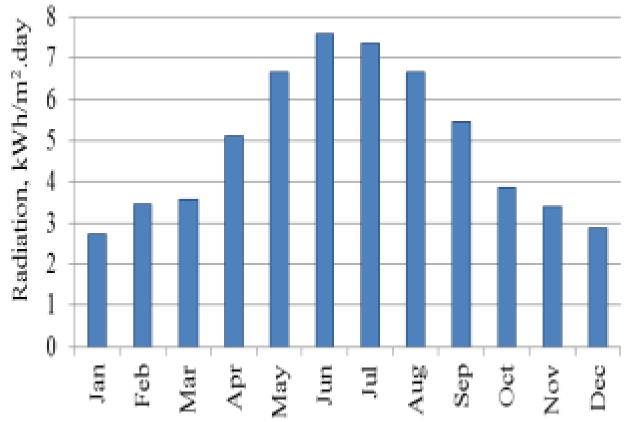


Fig. 3. Monthly average global radiation on horizontal plane in Kuwait [26].

The monthly clearness index of Kuwait can be calculated as [27]:

$$\overline{K}_T = \overline{H} / \overline{H}_o \tag{1}$$

Where $\overline{H}$ is the monthly average hemispherical radiation and $\overline{H}_o$ is the monthly average extraterrestrial radiation on a horizontal plane in the nth day of the year as specified in table 1 [27]:

$$\overline{H}_o = \frac{24 \times 3600 G_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \tag{2}$$

Where G_{sc} is the solar constant taken as 1367 W/m2 and δ is the solar declination given as:

$$\delta = (23.45^\circ)\sin[360^\circ(284+n)/365] \tag{3}$$

The solar declination depends on the day of the year, n, (with n = 1 for 1st January,)
The sun hour angle ωs is given by [27]:

$$\omega_s = \cos^{-1}[-\tan\phi\tan\delta] \tag{4}$$

Table 1 presents the mean day of each month, n and corresponding solar declination δ. Figure 4 shows the monthly average clearance index of Kuwait as calculated by equations 1-4.

Table 1. Suggested Average Day for Months and Values of n and δ [27].

Month	n for ith Day of Month	Date	n, Day of year	δ , Declination
January	i	17	17	-20.9
February	31 + i	16	47	-13.0
March	59 + i	16	75	-2.4
April	90 + i	15	105	9.4
May	120 + i	15	135	18.8
June	151 + i	11	162	23.1
July	181 + i	17	198	21.2
August	212 + i	16	228	13.5
September	243 + i	15	258	2.2
October	273 + i	15	288	-9.6
November	304 + i	14	318	-18.9
December	334 + i	10	344	-23.0

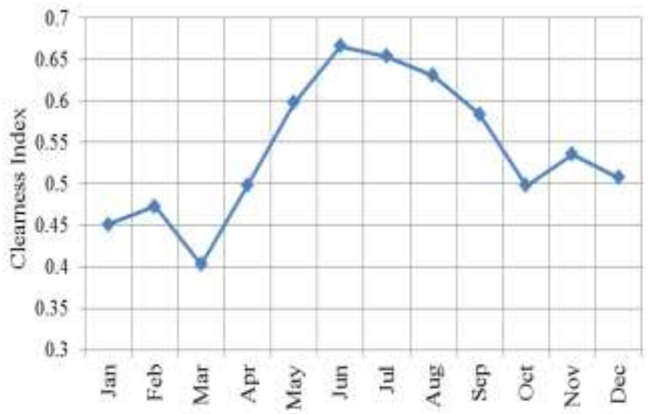


Fig. 4. Monthly average clearness index in Kuwait.

3. Dust Characteristics in Kuwait

Due to its low topographic position and little vegetation, Kuwait is vulnerable to sand storms. The storms crossing Kuwait carries substances of sediment containing 85% sand and the rest is silt [28]. Table 2 lists the grain sizes of the various sand types in Kuwait.

Table 2. Size of sand in Kuwait [28].

Soil type	Particle Diameter Range (mm)
Very fine sand	0.05 - 0.10
Fine sand	0.10 - 0.25
Medium	0.25 - 0.5
Coarse sand	0.25 - 0.5
Very coarse sand	1.0 -2.0

Al-Dousari [29] defined a dust storm in Kuwait as when the visibility is less than 1000 meter, where dust movement is low throughout winter, rises in March-April, and reaches its highest in July as shown in Figure 5.

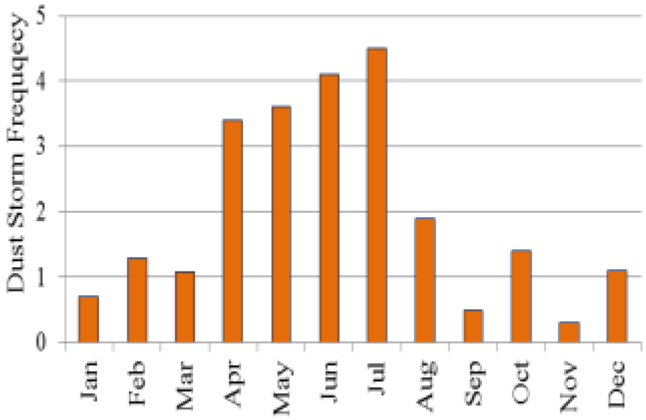


Fig. 5. Number of dust storm days in Kuwait in monthly average (2013) [29].

In order to assess the effect of dust on PV modules tested in this work, the optical characteristics of dust accumulated on PV modules located in coastal and desert sites in Kuwait were measured. The coastal site is Kuwait Institute for Scientific Research (KISR) while the desert site is Al-shagaya where the new solar farm project was setup. The collected dust was removed from an area of 12.5cm x 12.5cm and the weight of the sample was measured using Ohaus Advneturer digital weight scale with sensitivity of 0.001 mg. Furthermore, the spectral reflectance of the sample was measured using a Cary 100 spectrophotometer and the transmittance of the sample was measured utilising a digital Hazemeter. The Malvern Mastersizer 2000 laser diffraction particle size analyser was used to identify the sand particles size from the dust samples as shown in figure 6. Figure 6 shows a comparison between coastal and desert dust particles in terms of cumulative distribution. This comparison indicates that the difference between both desert and coastal dust is insignificant. The maximum particle size for desert was 90 micrometres and 130 micrometres for the coastal dust.

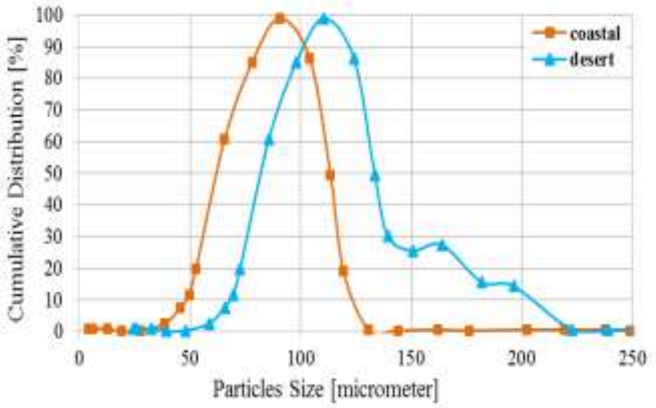


Fig. 6. Particles size distribution of the dust samples.

Figure 7 illustrates the reflectance and transmittance measurement process using the spherical light trapping. In this technique, the light source beam pass through spherical light trap into the sample container, then reflected to the detector which is the last element in the spectrophotometer. The silicon photodiode are typical detector used in spectrophotometer for the ultraviolet, visible and near-infrared regions.

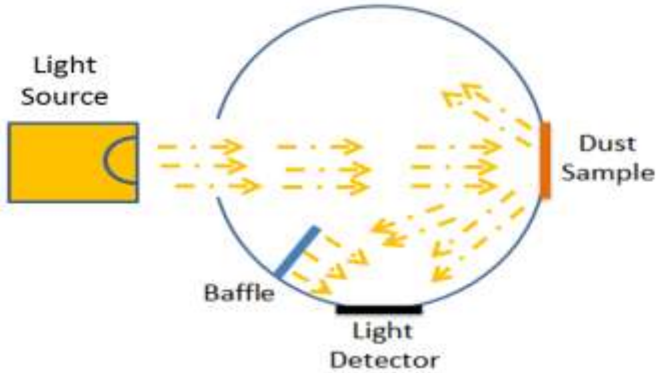


Fig. 7. Procedures of dust optical properties measurements [30].

Figure 8 shows the reflectivity measurement for the coastal and desert sands of three sizes namely 60, 80 and 100 microns over wavelength range of 300nm -1200nm. The reflectivity measurements were carried out using the Cary 100 spectrophotometer fitted with extended life LED light source. From figure 8 it is clear that as the particle size increases, the reflectivity increases. As for the effect of wavelength, the reflectivity increases with the increase in the wavelength reaching a maximum value at wavelength 800-900nm and then remains relatively constant. It can also be seen that as the particle size increases, the rate of increase in the reflectivity with the wavelength increases. Also, desert and coastal sand show similar reflectivity behaviour within 5% difference.

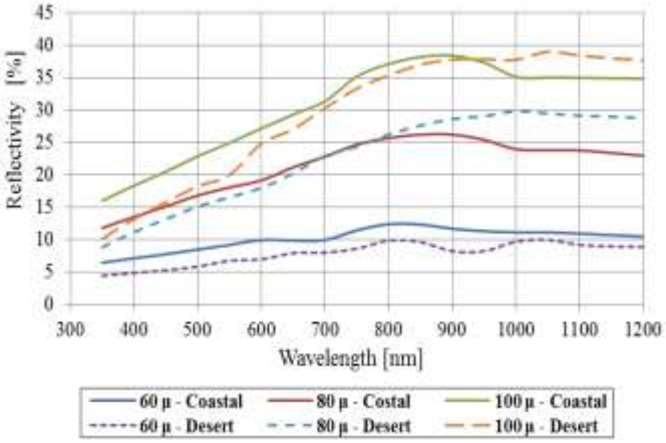


Fig. 8. Coastal and desert dust grains reflectivity

The transmittance measurement was carried out using spherical hazemeter (model EEL 057) with 0° degree illumination and LED lamp as light source. Equation (5) was used to calculate the samples Transmittance (T):

$$\%\text{Transmittance} = \frac{T\mathit{diffuse\ light}}{T\mathit{total\ light}} \times 100 \tag{5}$$

Sample container transmissivity is 93%.

Figure 9 shows the transmissivity of different grain sizes of coastal and desert dust, compared to the transmissivity of the glass sample container where the coastal dust has slightly (around 5%). higher transmissivity than the desert dust. From figures 8 and 9, it can be concluded that for the same particle size, the coastal and desert sand show similar optical characteristics.

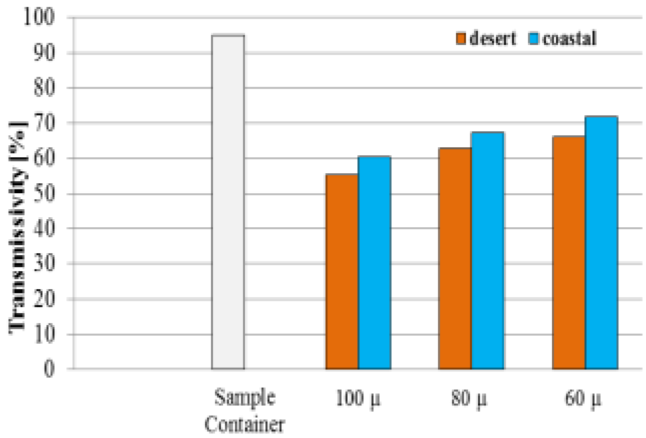


Fig. 9. The transmissivity of different grain sizes of coastal and desert dust.

4. PV Experimental Set up and Analysis

The outdoor measurements for the PV modules were performed in KISR at 30º N latitude. The PV module system consists of two pairs (clean and dusty) made from three different cell technologies as shown in table 3. The mounting structure was installed facing south and tilted at 30º which corresponds to the estimated latitude of Kuwait as shown pictorially in figure 10. The PV module power output, module temperature and in plane module radiation were measured. table 3 presents the performance of the three PV modules under Standard Testing Conditions (STC) of solar irradiance 1000 W/m2, air mass (AM) of 1.5 and cell temperature of 25 °C.

Table 3. Characteristics of tested PV Modules.

Technology	(HIT)	(SP)	(Poly)
Area (m2)	1.24	1.24	1.24
No. of cells	72 in series	72 in series	60 in series
Max.power	206.7 W	210W	179.3W
Max.voltage	41.3 V	40.0 V	29.4 V
Max.current	5.09 A	5.25 A	8.17 A

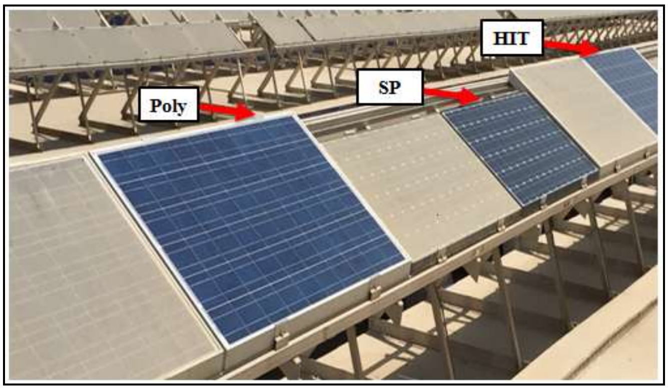


Fig.10. Installed PV Modules covered by dust [KISR].

Figure 11 shows schematically the PV modules' experimental testing setup. The experimental setup was equipped with a range of instrumentations including a Kipp & Zonen pyranometer with voltage sensitivity of 7 to 14 µV/W/m2, operational temperature range of -40oC to +80oC and +/-10W/m2 error in measuring the solar radiation on the module plane. The pyranometer was mounted on the inclined plane of the PV modules (30o) and cleaned on daily basis. Moreover, the temperature of each module was measured with temperature sensors attached on the centre of the back sheet of the PV modules investigated. The temperature sensors are thermally attached by a thermal conducting adhesive and insulated from the ambient temperature effect. The temperature sensor is PT100 with temperature range of -50/+300°C and +/- 0.6°C accuracy. Temperature sensors are coupled to IV tracer/maximum power tracker units which sweep 200-point IV data in every minute, along with maximum power output. The IV tracer maximum voltage and current readings are 250V and 10A with sweep speed of < 5 seconds per channel at 50 steps. The monitoring equipment preforms real time measurement of PV modules IV characteristics repeatedly recorded. The measurement of volts, ampere, power output and module temperature was carried out during 12 months periods. A planned data backup collection was taken every 1 month in addition to the regular data recording to indicate any non-uniformity of the modules outputs. The measured module output and meteorological data were transferred to a data acquisition system held at KISR renewable energy building.

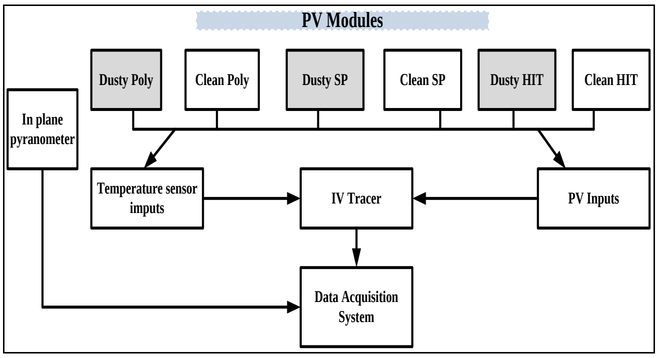


Fig. 11. Experimental data acquisition system at KISR.

The measurements were carried out during July 2013 with conditions of stable sunlight and calm airstreams throughout the day and figure 12 shows the measured in-plane solar radiation. The maximum power output point data sets that appeared once the solar radiation was between 100 and 1000 W/m², were chosen with the purpose of minimising the effect of large AM during the morning and the evening.

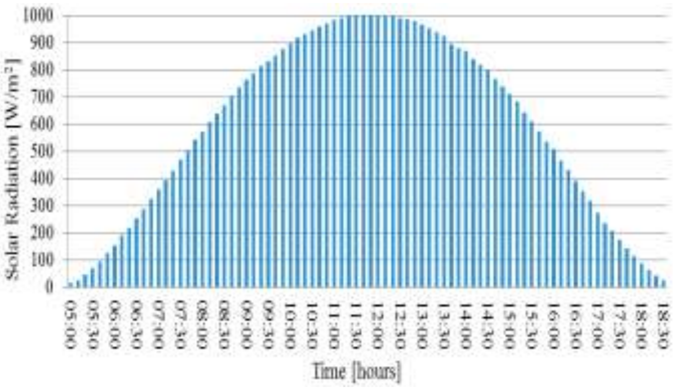


Fig. 12. Amount of solar radiation in Kuwait during the 1st of July 2013.

5. Results and discussion

Figure 13 shows the variation of the power generated by the clean PV modules during the 1st of July 2013. The power measured by each module was normalised to take into account the difference in the module surface area and represents the power out from a module with 1.24m2. It is clear from this figure that the SP module type has the highest power output of 183W at noon followed by HIT with 176.5W while the polycrystalline module have the lowest power output of 142W.

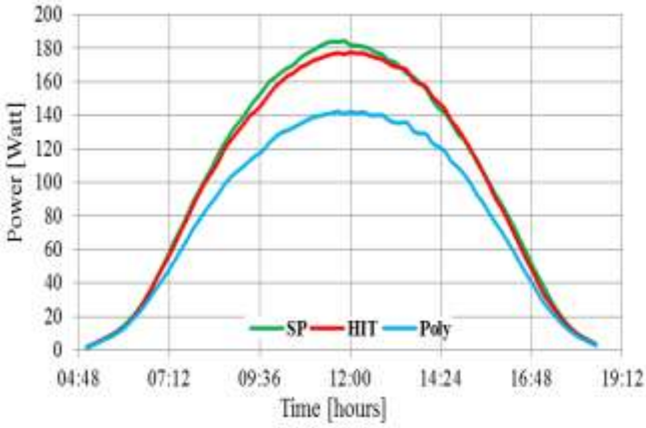


Fig. 13. Variation of maximum power generated by clean PV modules.

Figure 13 shows that the power output of the three PV modules are lower than those highlighted in table 3 at the standard testing conditions. This can be attributed to the higher module temperatures as shown in figure 14 reaching 65°C at noon. The power reduction due to the high ambient temperature is 27 (210-183), 29.5 (206-176.5) and 37 (179-142) for the SP, HIT and the polycrystalline respectively. It is clear from these measurements that the polycrystalline module was affected most by the high ambient temperature compared to the SP and HIT ones.

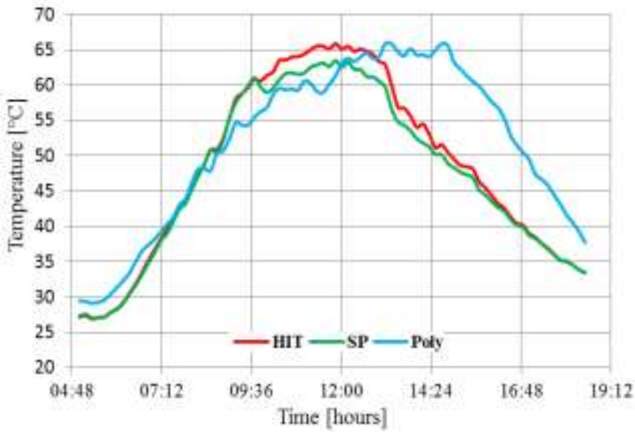


Fig. 14. Clean modules' temperature on the day.

Figure 15 shows that the power obtained from the three modules under the dusty conditions with dust accumulated over a period of 12 months and the module temperature shown in figure 16. It can be seen that the power has decreased compared to the results obtained when the PV modules were clean where the maximum power of the SP, HIT and polycrystalline modules are 130, 149 and 121W respectively. It is clear from this that the SP module is the most affected module by the dust with a drop of 53W while the polycrystalline is the least affected by the dust with a drop of 21W. The HIT has shown the highest performance of 149W maximum power output in Kuwaiti harsh environment.

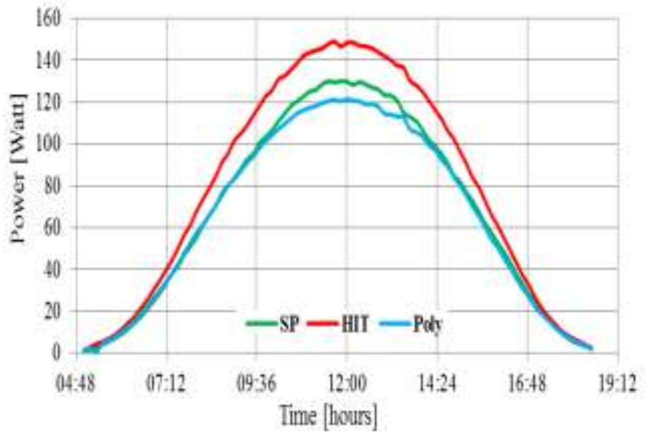


Fig. 15. Variation of maximum power output generated by the dusty PV modules.

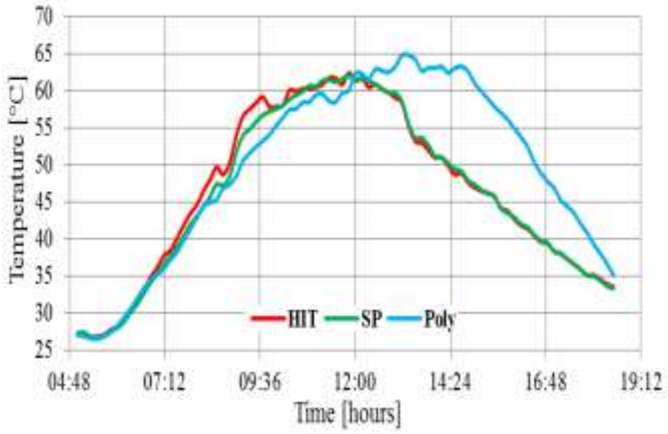
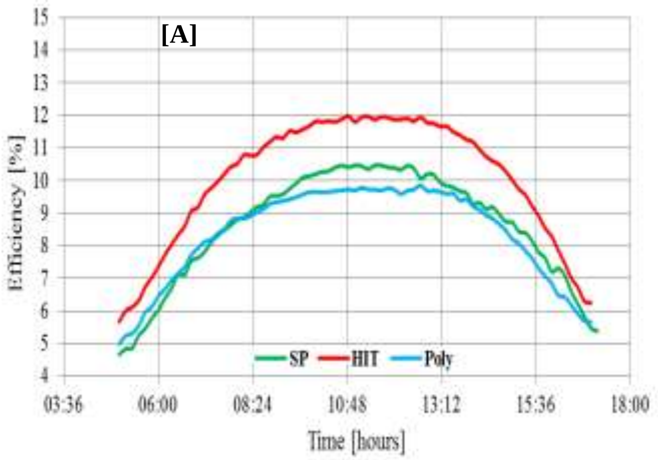


Fig. 16. Dusty modules' temperature on the day.

Figure 17 shows the efficiency variation of the three modules under clean and dusty conditions. It is clear that the SP module efficiency has dropped more significantly than the other two modules and the HIT has maintained the highest efficiency as summarised in table 4.



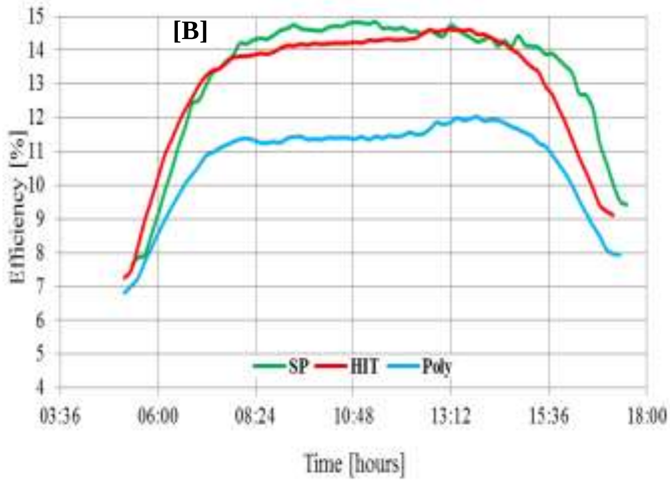


Fig. 17. Variation of PV modules efficiency during the day [A] clean and [B] dusty.

Table 4. Efficiency variation of PV modules condition.

Conditions	HIT	SP	Poly
STC	16.7	16.9	15
Clean	14.2	14.6	12
Dusty	12	10	9.5

Despite the different performance of the three modules, it is important to assess their economic viability for the Kuwaiti environment. Table 5 presents the area average cost of the PV modules, their life time and the cost per unit power produced averaged throughout the testing period as given in equation (6):

$$\text{Watt Cost} = \frac{Area\ Cost\ (\frac{£}{m^2})}{Power\ Output\ (\frac{W}{m^2})} \tag{6}$$

Table 5. PV modules areas cost effectiveness in clean and dusty conditions on peak solar radiation measurement.

PV module	Area cost (£/m^2)	Life time (year)	Clean PV cost at average power (£/W)	Dusty PV cost at average power (£/W)
Poly	129	25	1.57	1.89
SP	145	25	1.40	2.13
HIT	177	20	1.77	2.21

It is clear from table 5 that despite the higher performance of the HIT and SP modules under clean conditions, the polycrystalline module outperforms both SP and HIT under the Kuwaiti harsh conditions in terms of cost effectiveness where the cost of 1 W is £1.89 for the poly crystalline compared to £2.13 for the SP and £2.21 for the HIT.

6. Conclusion

Kuwait enjoys high solar radiation but suffers from dusty environment. This paper investigates the performance of three PV modules namely SP, HIT and Polycrystalline under clean and dusty conditions where the dust accumulated over the modules through a period of 12 months. Also, work was carried out to characterise the optical properties of sand from coastal and desert sites in Kuwait. Regarding the sand optical characteristics, results showed that for the same size of sand particles, similar (within 5% difference) optical properties were measured. AS for the performance of the PV modules, measurements showed that this that the SP module is the most affected module by the dust with a drop of 53W while the poly crystalline is the least affected by the dust with a drop of 21W where the efficiency of the SP module has dropped more significantly than the other two modules and the HIT has maintained the highest efficiency. Taking the cost and lifetime of the modules into account, the polycrystalline module outperforms both SP and HIT under the Kuwaiti harsh conditions where the cost of 1 W is £1.89 for the poly crystalline compared to £2.13 for the SP and £2.21 for the HIT.

References

[1] Al-Enezi, F., J. Sykulski, and N.A. Ahmed, Visibility and potential of solar energy on horizontal surface at Kuwait area. Energy Procedia, 2011. 12: p. 862-872.

[2] KUNA, Kuwait eyes alternative energy to meet growing demand – Solar power station ready by 2016, in Kuwait times. 2014, Ministry of Information Kuwait: Kuwait.

[3] Al-Hurban, A.E. and A.N. Al-Ostad, Textural characteristics of dust fallout and potential effect on public health in Kuwait City and suburbs. Environmental Earth Sciences, 2010. 60(1): p. 169-181.

[4] Denholm, P., et al., Solar energy: The largest energy resource. Generating Electricity in a Carbon-Constrained World, FP Sioshansi, ed., Academic Press, California, 2010: p. 271-302.

[5] Mani, M. and R. Pillai, Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. Renewable and Sustainable Energy Reviews, 2010. 14(9): p. 3124-3131.

[6] Wakim, F., Introduction of PV power generation to Kuwait. Kuwait Institute for Scientific Researchers, Kuwait City, 1981.

[7] Hasan, A. and A. Sayigh, The effect of sand dust accumulation on the light transmittance, reflectance, and absorbance of the PV glazing. Renewable Energy. Technology and the Environment, Pergamon Press, Oxford, 1992: p. 461-466.

[8] Qasem, H., et al., Effect of dust shading on photovoltaic modules. 26th European Photovoltaic Solar Energy Conference and Exhibition, 2011.

[9] Al-Hasan, A.Y. and A.A. Ghoneim, A new correlation between photovoltaic panel's efficiency and amount of sand dust accumulated on their surface. International Journal of Sustainable Energy, 2005. 24(4): p. 187-197.

[10] Sayigh, A., S. Al-Jandal, and H. Ahmed. Dust effect on solar flat surfaces devices in Kuwait. in Proceedings of the workshop on the physics of non-conventional energy sources and materials science for energy. 1985.

[11] Adinoyi, M.J. and S.A. Said, Effect of dust accumulation on the power outputs of solar photovoltaic modules. Renewable Energy, 2013. 60: p. 633-636.

[12] Salim, A., F. Huraib, and N. Eugenio. PV power-study of system options and optimization. in EC photovoltaic solar conference. 8. 1988.

[13] Nimmo, B. and S.A. Said. Effects of dust on the performance of thermal and photovoltaic flat plate collectors in Saudi Arabia-Preliminary results. in Alternative energy sources II, Volume 1. 1981.

[14] El-Shobokshy, M.S. and F.M. Hussein, Effect of dust with different physical properties on the performance of photovoltaic cells. Solar energy, 1993. 51(6): p. 505-511.

[15] El-Shobokshy, M., A. Mujahid, and A. Zakzouk, Effects of dust on the performance of concentrator photovoltaic cells. Solid-State and Electron Devices, IEE Proceedings I, 1985. 132(1): p. 5-8.

[16] Touati, F., et al. Effects of environmental and climatic conditions on PV efficiency in Qatar. in International Conference on Renewable Energies and Power Quality (ICREPQ'13). 2013.

[17] Alnaser, N.W., Dust Accumulation Study on the Bapco 0.5

[18] MWp PV Project at University of Bahrain. International Journal of Power and Renewable Energy Systems, 2015. 2(1): p. 53.

[19] Al Hanai, T., et al., Environmental effects on a grid connected 900 W photovoltaic thin-film amorphous silicon system. Renewable energy, 2011. 36(10): p. 2615-2622.

[20] Ibrahim, M., et al. Advanced Photovoltaic test park in Egypt for investigating the performance of different module and cell technologies. in Proceedings of the 24th Symposium Photovoltaic Solar Energy, Staffelstien, Germany. 2009.

[21] Hassan, A., et al., Effect of airborne dust concentration on the performance of PV modules. J. Astron. Soc. Egypt, 2005. 13(1): p. 24-38.

[22] Al-Alawy, I.T., Wind and other factor requirements to solar energy applications in Iraq. Solar & Wind Technology, 1990. 7(5): p. 597-600.

[23] Boykiw, E., The effect of settling dust in the Arava valley on the performance of solar photovoltaic panels. Boykiw thesis, meadville environmental science department, allegheny college, Pennsylvania, 2011.

[24] Pavan, A.M., A. Mellit, and D. De Pieri, The effect of soiling on energy production for large-scale photovoltaic plants. Solar Energy, 2011. 85(5): p. 1128-1136.

[25] Sanusi, Y., The performance of amorphous silicon PV system under Harmattan dust conditions in a tropical area. Pacific Journal of Science and Technology, 2012. 13(1): p. 168-175.

[26] Al-Dowaysan, K., Ambient Temperature Report 2013. 2014, Directorate General of Civil Aviation, Meteorological department Kuwait.

[27] Kuwait, E.P.A.o., Kuwait Environmental Report 2014. 2014, Environment Public Authority of Kuwait: Kuwait.

[28] Duffie, J.A. and W.A. Beckman, Solar engineering of thermal processes. Vol. 3. 1980: Wiley New York etc.

[29] Al-Dousari, A.M. and J. Al-Awadhi, Dust fallout in northern Kuwait, major sources and characteristics. Kuwait Journal of Science, 2012. 39(2A): p. 171-187.

[30] Al-Dousari, A.M., J. Al-Awadhi, and M. Ahmed, Dust fallout characteristics within global dust storm major trajectories. Arabian Journal of Geosciences, 2013. 6(10): p. 3877-3884.

[31] Bohren, C.F. and D.R. Huffman, Absorption and scattering of light by small particles. 2008: John Wiley & Sons.