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Performance of Silicon Heterojunction Photovoltaic modules in Qatar climatic conditions

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ABSTRACT

We report on the performance of two cell technologies: Silicon Heterojunction (SHJ) and conventional diffused junction n-type mono-crystalline silicon Photovoltaic (PV) arrays, under a harsh environment condition with high temperature and dust accumulation, typical to Qatar. A comparison of the energy yield and Performance Ratio (PR) at plane of array global irradiance as well as module temperature (T_{mod}) of the two technologies is presented. The SHJ arrays showed a higher energy yield as compared with the conventional arrays thanks to the higher efficiency of the SHJ. The results showed also that dust accumulated on PV modules may cause a drop in the PR of up to approximately 15% if the module is not cleaned for one month. Scheduled module cleaning or raining will return the PR close to its initial value.

1. Introduction

Effects of environmental conditions on PV performance are important to determine the PV technology that produces the best energy yield at a specific location. The literature is rich with comparative studies on PV performance under different climatic conditions and locations [1–6]. However, limited data are available on PV performance in Qatar with particular high temperatures, high soiling rate and humid climate conditions. These data are important for the deployment of solar energy in Qatar, particular, by selecting the technology that yields the maximum and stable performance in hot climatic conditions.

It is known that solar irradiance and temperature have a significant impact on PV performance, particularly for crystalline silicon, as the module temperature rises; the maximum power output is reduced. Several studies have reported the variation of PV module performance as a function of module temperature. This mainly depends on the temperature coefficient of the cell technology [7–10].

The first Silicon Heterojunction (SHJ) solar cells with an efficiency of 18% were developed by *Sanyo* [11]. Generally, the SHJ cells are known to exhibit a high conversion efficient and an improved performance as compared with the conventional diffused junction silicon cells [12,13]. However, SHJ cell has a lower short-circuit current density J_{sc} as compared with the one obtained from conventional mono-crystalline silicon. This is due to the blue and red parasitic absorption at the cell front and rear, respectively [14,15].

2. Experimental and methods

2.1. Outdoor measurement (Solar Test Facility)

A total of 150 kWp different PV technologies, such as, mono-crystalline (m-cSi), multi-crystalline silicon (mc-Si), micro-morph (a-Si/μc-Si), cadmium telluride (CdTe) and copper-indium-gallium-diselenide (CIGS) were installed at the Solar Test Facility, Qatar Science and Technology Park, Doha (Fig. 1). The coordinates of Doha is: latitude 25.33° North and longitude 51.43° East. The metrological station provides in interval of one minute real-time data of the three solar irradiation components measured using Kipp & Zonen CMP21 pyranometers; the direct radiation from the sun (Direct Normal Irradiance DNI), the scattered radiation from the direct radiation by the atmosphere (Diffused Horizontal Irradiance DHI) and the total solar radiation (Global Horizontal Irradiance GHI). In addition, the Global Plane of Array (G-POA) irradiance; where the irradiance sensor is mounted on the similar

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Nomenclature

T_{mod}	Module temperature [°C]
V_{oc}	Open-circuit voltage [V]
I_{sc}	Short-circuit current [A]
J_{sc}	Short-circuit current density [A]
P_{max}	Maximum power output [W]
V_{mpp}	Voltage at $P_{\max}$ [V]
I_{mpp}	Current at $P_{\max}$ [A]
FF	Fill factor
η	Module efficiency [%]
α	Temperature coefficient of P_{max} [%/°C]
β	Temperature coefficient of V_{oc} [%/°C]
γ	Temperature coefficient of I_{sc} [%/°C]
PR	Performance Ratio [−]
Y_A	Energy yield [Wh/Wp]
$E_{A,d}$	Daily array DC energy output [Wh]
P_{norm}	Peak power at Standard Testing Condition STC [Wp]
Y_R	Reference yield
G_{POA}	Global irradiance at Plane of Array POA [Wh/m^2]
G_{STC}	Irradiance at Standard Testing Condition STC [W/m^2]

Fig. 1. Photo of the Solar Test Facility, 150 kWp different PV technologies installed at the Qatar Science and Technology Park (QSTP), Doha, Qatar.

orientation of the PV module at fixed 22° tilt-racks due to South, ambient air temperature, wind speed and direction were also monitored continuously.

The data acquisition system provides IV characteristics of the PV strings under real operating conditions at one minute time interval. From each array, the DC and AC current and voltage and the power output were monitored. The module temperatures (T_{mod}) were measured using three thermocouples (SOL.Connect Sensor T, Platinum resistance temperature sensor PT 1000) mounted on the back of every string with an accuracy of ±1 °C.

2.2. PV system

High efficiency PV technologies likely to be adapted to high temperature environment were selected in this study; in particular, n-type diffused junction mono crystalline silicon and SHJ modules from two different manufacturers were installed. The installed capacity for the mono crystalline and SHJ is 2.1 and 1.96 kWp, respectively, was used to calculate the specific energy yield. No degradation of the PV module encapsulants was observed during the testing period.

Two solar cell technologies are under study in this paper: conventional diffused-junction solar cells with Aluminium Back Surface Field (BSF), hereafter called conventional, and Silicon Heterojunction (SHJ) that consists of a mono-crystalline silicon substrate as base and on both sides thin films of hydrogenated amorphous silicon for junction formation, passivation and surface field. One of the important characteristics of the latter is the low temperature coefficient at maximum power in the order to of −0.3%/°C obtained mainly thanks to the high V_{oc} [16,17]. Module specifications at Standard Test Conditions (STC) (AM1.5G, 1000 W/m^2 and 25 °C) are given in Table 1.

3. Method

During the testing period from January to December 2014, the back surface module temperatures (T_{mod}) of three modules in each string were measured and averaged during the daylight. From the monitored data, the energy yield (Y_A) and the Performance ratio (PR) were used to compare the performance of the two technologies.

The Performance Ratio (PR) is a parameter used for performance comparison according to the recommendations of International Electrotechnical Commision standard IEC-61724 [18]:

$$PR = \frac{Y_A}{Y_R} \tag{1}$$

where Y_A is the energy yield in [Wh/Wp] defined as:

$$Y_A = \frac{E_{A,d}}{P_{\rm norm}} \tag{2}$$

where $E_{A,d}$, is the daily array DC energy output in [Wh] and P_{norm} is the peak power at Standard Testing Condition STC in [Wp].

Y_R is the reference yield defined as:

$$Y_R = \frac{G_{POA}}{G_{STC}} \tag{3}$$

where G_{POA} is the total incident irradiance at Plane of Array POA in [Wh/m^2] and G_{STC} is the irradiance at STC in [W/m^2].

4. Results and discussion

4.1. Meteorological data

The annual GHI measured at the Solar Test Facility during the whole year of 2014 is 2217 kWh/m^2/year, which is comparable with the yearly averaged value of 2113 kWh/m^2 measured over Qatar during the period 2007–2012 [19].

From Fig. 2, after a gradual increase in GHI and G-POA, a peak value is reached during June and July. The monthly average of 200 kWh/m^2/month was measured for G-POA, while GHI measured 185 kWh/m^2/month. The variation between GHI and G-POA shows an increase in G-POA during the winter months from September to December due to the change of the sun direction with respect to the module tilting angle. Average monthly DNI of 151 kWh/m^2 and average DHI of 68 kWh/m^2 were measured. The month January showed the lowest DNI value. Finally, a minimum DHI value was reached during the month of December.

As shown in Fig. 2, an increase in the average air ambient temperature as irradiance increases was also observed from January to July to reach 40 °C; this increase in ambient temperature