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Conference Paper

Three-Year Performance Evaluation of Single Junction Amorphous Solar Cells Grid-Connected Power Station in Libya

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Photovoltaic (PV) conservation of solar energy is one of the most promising sources of future energy. Grid-connected PV systems are widely used in many countries, but in Libya it is just started. A PV grid-connected of 24 KWP PV system has been installed as a pilot project to deliver AC energy to the Tripoli University electric grid; the system is of single junction amorphous solar cells which were erected in Sep. 2009; it consists of 240 Mitsubishi thin film amorphous PV Modules of MA100T2 type capable of supplying 100 Watts of DC power each, five inverters of type SMA Sunny Mini Central, and the system is equipped with a data logger to record all important parameters. In this paper the evaluation of the PV system performance was carried out according to the European guidelines of the PV system operation. The results of the measured parameters, namely, the performance ratio, AC energy yearly yield, the temperature dependent, and the system efficiency, showed that the system is performing better than the deigned parameters.

1. Introduction

Early applications of PV systems were made as standalone PV systems, while at the end of the last century the era of grid-connected PV systems became a reality as a result of high fuel prices [1]. Research and development were focused on utilizing different technologies and PV systems for better performance toward a reliable and stable power sources for a sustainable future energy [2, 3].

In Libya standalone PV systems were put into work since 1976, in communication as a power supply for isolated repeater stations. Later applications came as rural electrification, water pumping, and cathodic protection; many studies have been conducted to evaluate the performance of utilizing standalone systems in Libya [4–6]; the evaluations of some of these systems showed that the systems were performing with very high performance ratio, and high global system efficiencies; in 2009 few grid-connected PV systems were installed to evaluate these kinds of applications with Libyan electric grid. One of the grid-connected systems which was installed in Tripoli University in 2009 is a 24 KWp single junction amorphous Solar Cells grid-connected power station.

The construction of a 24 KWp grid-connected solar station came as a result of signing of a Memorandum of Understanding between Tripoli University and Mitsubishi Corporation. The system was constructed from 240 Mitsubishi thin film PV Modules of MA100T2 type capable of supplying 100 Watts of DC power each with a total area of 382.77 m^2 [7]. The tilt angle of modules is equal to 25°. The system employs five pieces of SMA Sunny Mini Central inverters capable of converting 5 KW of ac power for each. The data logger, Sunny Webbox, is used for collecting and transferring data measured by the sensors of the station to a computer system in order to be processed. Since the system installation, it has been working for almost three years of operation yielding a net energy production of 120 MW by the end of September 2012. The last three months of 2009 were

Figure 1: Array field.

the first period of the station's exploitation. The three years following 2009 are the ones in which complete data sets for the station have been collected to be evaluated to obtain real indications of the station's outputs fed into the power grid; the Libyan electric network was not reliable during the period of the data collection; some of the reasons included the Libyan revolution in 2011, where the network was down most of the time, which will have a great effect on the performance of the PV station.

2. System Description and Design Performance Parameters

The PV system was constructed from 240 MA100T2 a-Si PV modules, a layout of the PV system is illustrated in Figure 2 [7].

2.1. System's Location. The system is located at latitude 32, 90 N, longitude 13, 18 deg E, and elevation 20 m.

2.2. System Designed Performance Parameters Annually. The PV system is to deliver AC energy into Tripoli University electric network, with the following parameters.

System AC energy: 35.085 MWh.

AC Kwh/KWp: 1461.6.

AC kWh/m^2: 201.

Average performance ratio 74.7%.

2.3. Description of the PV Power Station. The PV power station is a 24 KWp grid-connected station, comprised of 240 Mitsubishi a-Si PV modules MA100T2 having a total area of 382.77 m^2. The Modules were constructed on a plane angle equal to 45° as shown in "Figure 1". The field array is divided to five subarrays each of 48 modules; DC to AC power converters fabricated by SMA Company of the type SMA Sunny Mini Central are used for conveying the AC power generated to the utility grid. The data measured by the station's sensors is monitored and transferred to the computer system through SMA Sunny Webbox, and then these measurements are classified and evaluated to determine the station's performance and other important indicators which will help to know the feasibility of utilizing this type of PV generating stations on the southern shore of the Mediterranean.

2.4. Meteorological Station Description. The meteorological station employed is built up on the same level on which the solar modules have been constructed. The station has the fundamental function of sensing and measuring the weather conditions where the station is located. The most important parameters recorded by the station are the total horizontal irradiation, direction of wind and its velocity, ambient temperature, module temperature, and the atmospheric pressure. One other feature contained by the station is that it is able to give measurements of the amount of carbon dioxide reduced (CO_2).

3. Measurements

The station under investigation was put into work in Oct. 2009, the measurements were recorded from the startup day to September 2012, the station was connected to the Tripoli University's electric grid which was subjected to many interruptions during 2011 and 2012.

3.1. Measurements of Irradiation Level and AC Energy Production. The grid-connected PV station has three pyrometer sensors to measure the irradiation levels. These pyrometers are installed on the same level at which the PV modules are constructed. The meteorological station started to record the data measured for the irradiation level when inverters start functioning which means the insulation levels are high enough to make the whole system transfer the energy to the utility grid. The investigation of the station started in the last three months of 2009 and is still being continued. Also, the complete set of data measured is available to us during the period of investigation. Additionally, the measurement of AC energy production delivered to the utility grid is recorded. "Figure 3" shows measurements of irradiation levels collected starting from Oct. 2009 to the end of September 2012, and also measurements of the energy showed that the station has produced **120** MWh over the course of its operation.

From the measured AC energy which is compared on a monthly basis, the yearly output energy is found to be 38.9 MWh which is 11% more than the designed energy; the maximum monthly energy produced is 4002 KWh, while the monthly average AC energy is 129 KWh, with a maximal 5.38 KWh/KWp per day, and a yearly 1963 KWh/KWp which is 34% more than the designed parameter. The monthly average radiation is 124.6 KWh/m^2, while the maximum average monthly solar radiation measured is 139.01 (kWh/m^2/month) recorded in July months.

3.2. The PV System Performance Evaluation. The analysis of this PV grid-connected station's performance is based on the European Guidelines [8, 9], where the key parameters that have been used to evaluate the performance are energy yield, daily monthly yield (DMY), and performance ratio. For the sake of our analysis, DMYs and performance ratios

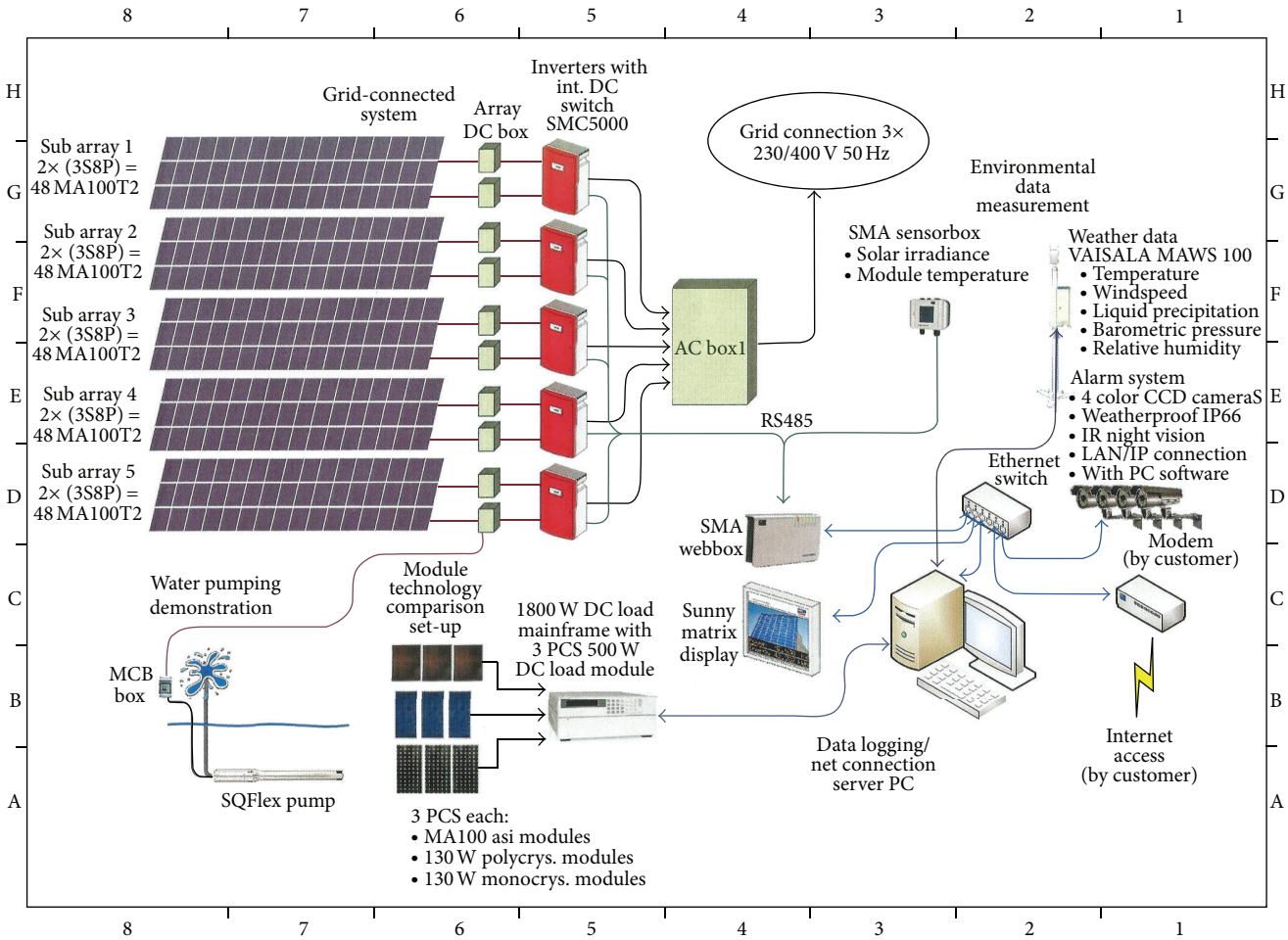

Figure 2: A part of the PV arrays of the 24 KWp grid-connected station described [7].

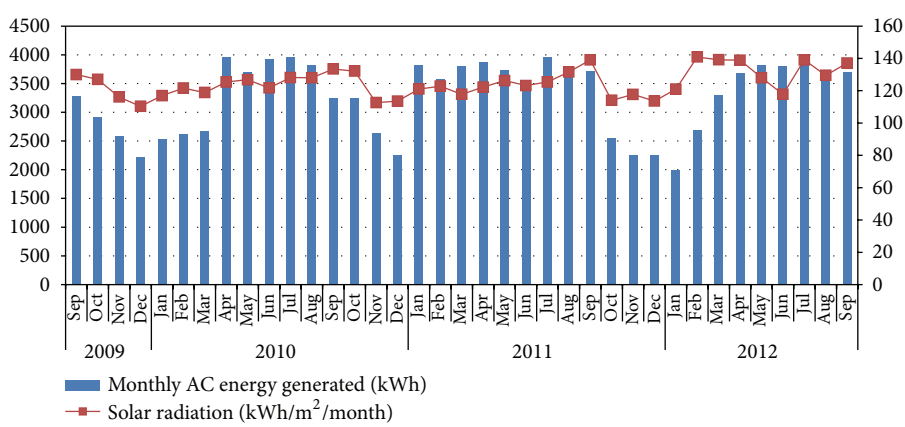

Figure 3: Measurements of irradiation levels and AC energy productions.

have been used as key indicators of the grid-connected PV systems.

Through the period of evaluation Oct. 2009–Jul. 2012, the daily average measurements were used to evaluate the PV performance, and then the monthly daily mean yield (DMY) and performance ratio (PR) are calculated. The DMY is calculated using

$$\mathrm{DMY} = \frac{E_{\mathrm{out}}}{P_o}, \tag{1}$$

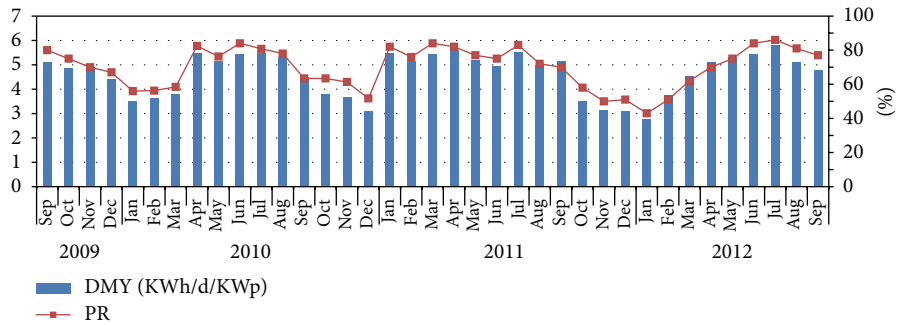

Figure 4: The monthly average performance ratio results and the corresponding mean daily monthly yields during the period of investigation.

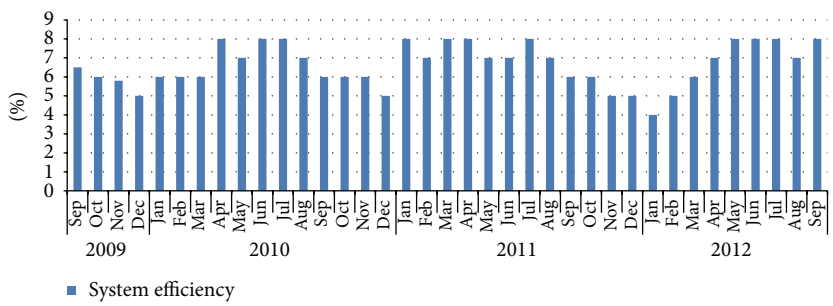

Figure 5: System efficiency through the period of the measurements.

where E_{out} is the total AC energy output of the system in kWh, P_o is the total rated system power in kWP.

The performance ratio (PR) which is a measure of how much power is utilized from the system and it is calculated using

$$\text{PR} = \frac{E_o/P_o}{H_I/G_o}, \tag{2}$$

where H_I is the daily total irradiation in kWh/m^2, G_o is the reference irradiance (= 1 kW/m^2).

"Figure 4" shows the monthly daily mean yield and performance during the period of study.

From the figure, the average daily monthly yield (DMY) is 4.63 KWh/KWp, while maximum daily monthly yield is 5.8 KWh/KWp in July 2012. The average performance ratios during the measurement period is 70%, which is 6% less than the designed parameter, and this is due to the unavailability of the electric grid part of it due to the Libyan revolution, 2011. The maximum performance ratio recorded is 86% in July 2012.

4. System Efficiency

The monthly system efficiency was calculated based on

$$\text{Eff} = \frac{E_{\text{out}}}{A_M G_i}, \tag{3}$$

where E_{out} is the total monthly generated energy, A_M is the total module area, and G_i is the solar radiation.

From Figure 5, it can be seen that the global system efficiency as given by (3) was drawn versus months during the measurements period in Figure 5, from the figure it was found that the average system efficiency is 7%, while the maximum efficiency is 8%. The maximum efficiency was recorded in spring months, because the temperature being at its best related to the module temperature, finally no degradation in the system efficiency was recorded.

5. Temperature Dependence

To study the effect of the ambient temperature on the module temperature, a comparison was made between ambient and module temperature in four days of the year, 21st of Mar., June, September, and December. "Figure 6" shows the module temperature and the ambient temperature.

The temperature of the PV module during the day showed that heating of the module occurred in the afternoon period due to higher solar radiation levels. From "Figure 6" the monthly average module and ambient temperatures are shown; the PV modulus's temperature behavior has been compared during the period of investigation of 2011, where it can be readily seen that the maximum module temperature of 61°C has been recorded on June 21 at 12:00 pm which really means that this period of time is in the summer where the maximum temperatures can be observed. In Dec. 21, the lowest ambient and module temperature were recorded where on this day of December 21 has never exceeded 11°C.

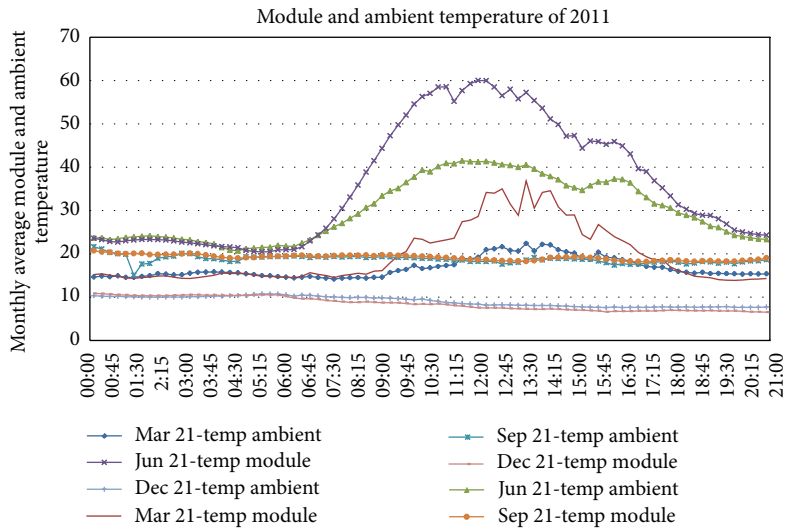

Figure 6: Temperature of the PV module and ambient temperature versus time of the days on 21st of Mar. 2011, 21st of June, 21st of September, and 21st of December.

6. Conclusion

In this paper, performance investigation resulting from the first grid-connected PV system of Tandem thin film modules fabricated of amorphous silicon has been reported. The following conclusions can be drawn for the period of investigation from Oct. of 2009 to September 2012.

(1) Average monthly PV energy generated was **3961.24** KWh.

(2) Average monthly performance ratio of the park was 70%.

(3) As a conclusion, the integration of grid-connected PV systems to the transmission network of Libya is promising to be reliable and satisfactory for the reason that the system showed a high performance ratio of 86% where the maximum average monthly solar irradiation was 139.01 (kWh/m^2/month). The problem facing PV grid-connected systems is that the DC to AC converters, inverters, have faced some problems that made them not to restart converting the DC power to AC energy. It is also concluded that the temperature dependence of this amorphous Si thin film modules is less compared to other technologies installed in Libya; that is, amorphous Si modules have proved its reliability. Overall, based on this performance evaluation, grid-connected PV systems are seen to be valuable solutions for electricity generation for the Mediterranean countries if only long-term tests and investigations are carried out.

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References

[1] J. H. So, H. M. Hwang, B. G. Yu et al., "A detailed performance results of grid-connected pv system by long-term field test," in *Proceeding of the 24th European Photovoltaic Solar Energy Conference*, pp. 21–25, Hamburg, Germany, September 2009.

[2] J. J. H. So, H. M. Hwang, B. G. Yu, J. S. Yoo, G. J. Yu, and J. Y. Choi, "A detailed performance results of grid-connected PV system by long-term field test," in *Proceedings of the 24nd European Photovoltaic Solar Energy Conference*, p. 4045, 2009.

[3] J. H. So, B. G. Yu, G. H. Kang, H. M. Hwang, G. J. Yu, and J. Y. Choi, "Performance results and analysis of 3 kW grid-connected PV systems," in *Proceedings 22nd European Photovoltaic Solar Energy Conference*, p. 3008, 2007.

[4] M. I. Saleh, M. I. Abouhdima, M. B. Gantrari et al., "Performance comparison of a stand alone PV systems used in rural electrification and a PV system in communications," in *Proceeding of the Libyan Arab International Conference on Electrical and Electronic Engineering LAICEEE*, pp. 20–23, Tripoli, Libya.

[5] I. M. Saleh, I. Abouhdima, and M. B. Gantrari, "Performance of thirty years stand alone photovoltaic system," in *Proceeding of the 24th European Photovoltaic Solar Energy Conference, taking place in Germany*, 2009.

[6] I. M. Saleh, I. Abouhdima, and M. B. Gantrari, "Six years performance of standalone PV systems used to electrify an isolated village in Libya," in *Symposium of Small PV-Applications, Rural Electrification and Commercial Use-Ulm*, Germany, May 2009.

[7] Station Catalog, 2009.

[8] K.-L. Yen, C.-T. Tsai, and M.-S. Bai, "Performance evaluation of monocrystalline and am-orphous silicon Pv systems intaiwan," in *Proceedings of the 24th European Photovoltaic Solar Energy Conference*, pp. 21–25, Hamburg, Germany, September 2009.

[9] Photovoltaic System Performance Monitoring-Guidelines for Measurement, Data Exchange, and Analysis 61724, IEC Standard, Geneva, Switzerland, 1998.