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ANALYSIS OF PHOTOVOLTAIC PROJECTS IN A MEDITERRANEAN ISLAND

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ABSTRACT: The paper presents an analysis of the four grid-connected systems installed in Malta and monitored by the Institute for Energy Technology of the University of Malta. The systems have varying power ratings, orientation and tilts. Three systems had stationary solar modules, while the fourth one used an active tracking device. The purpose of this study was to evaluate the performance of different systems under the local weather conditions of a typical Mediterranean country. Comparison to other systems in EU countries was made and answers to frequently asked questions were found. The mean monthly Performance Ratio of the systems ranged between 0.51 and 0.80, while the final yield was reported to be between 2.76kWh/kWp/day and 3.61kWh/kWp/day. The final efficiency was also found to be between 5.1% and 7.1%. This compared favourably with results reported by European researchers such as in the Thermie Project. The inverters proved to be safe and did respond as expected during times of grid disturbance. In view of Malta's new membership in the European Union, this study will be an essential tool to support future widespread applications of solar electric systems in Malta.
Keywords: Rooftop – 1: Small Grid-connected PV Systems – 2: Solar Home System – 3

1. INTRODUCTION

The monitoring and installation of grid-connected systems by the Institute for Energy Technology (IET) of the University of Malta started in 1996. The data collected in Marsaxlokk (lat. 35.8ºN, long. 14.4ºE) at 15 m altitude has helped to comprehend the behaviour and potential for photovoltaic (PV) systems in Malta. In 2002, two systems were also commissioned for private entities, i.e. a residence "Mytton Lodge" and a factory "Baxter (Malta) Ltd". The purpose of this paper is to make a comparison of the performance of four different grid-connected systems existing in the country for the period ranging from June 2002 to December 2003.

2. THE SOLAR POTENTIAL

Figure 1 shows the daily mean of solar radiation taken by six different solar pyranometers.

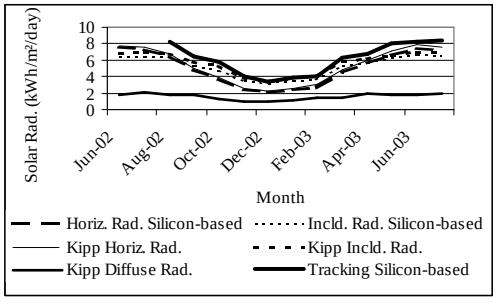

Figure 1 – Mean daily solar radiation for the period June 2002 to July 2003 taken at Marsaxlokk, Malta

Three Kipp & Zonen thermopile pyranometers were used to measure the global horizontal, global diffuse and inclined (36º to the horizontal) radiation. The other three readings were collected by using silicon cell based pyranometers that measured the global horizontal radiation, inclined (36º to the horizontal) radiation and on the plane of the PV tracking system.

The Kipp & Zonen pyranometers had higher values of irradiance, since unlike the silicon cell-based instruments, they are sensitive to the whole solar spectrum. Nevertheless, the silicon readings were the ones used in this paper, since they characterized the actual solar potential available for the silicon PV cells. They could be identified as being consistent and reliable, when compared to the Kipp & Zonen Pyranometer readings.

Since there was no radiation data taken for the two privately owned solar systems of Mytton Lodge and Baxter, the PV F-Chart software was used to predict the solar radiation on the planes of the solar arrays. These were at 30º to the horizontal and azimuth of 40ºSW and at 25º to the horizontal and azimuth 0° respectively.

By finding the predicted radiation ratio between each of the two planes and the horizontal, as given by the PV F-Chart software, the actual mean daily radiation could be found by multiplying these ratios by the actual values obtained from measured data of the silicon-cell based horizontal pyranometer at Marsaxlokk. These values could be very representative of the two sites since the comparison between values measured at the horizontal and at 36º compared favourably with the PV F-Chart prediction.

3. SYSTEMS DESCRIPTION

All the PV systems analysed faced the true geographic south except for "Mytton Lodge" where the modules were fixed to a 40º SW wall. In Table 1, a description of the inspected systems is presented to allow a better understanding of the differences between them.

4. DATA ANALYSIS

The period of analysis for the systems ranged from June 2002 to July 2003. During this time data was collected both for radiation (as presented in Figure 1) and for performance of the mentioned systems in 15-minute mean data files. The performance data included among

others power output, grid impedance, grid voltage, grid current, PV voltage and PV current.

Table 1: Inspected Systems in Malta

ID.	IET Static	IET Tracking	Mytton Lodge	Baxter
Type	Static	Traxle Tracking	Stationary	Stationary
Location	M'Xlok	M'Xlokk	Madliena	Marsa
Azimuth	0º	0º	40ºSW	0º
Tilt Angle	36º	36º	30º	25º
Cell Type	Poly-Si	Poly-Si	Mono-Si	Poly-Si
Modules	30 Solarex MSX 60	6 Solarex MSX 60	24 Solar Power SPL 60	33 Shell RSM 90
Nominal Power	1.8 kWp	0.36 kWp	1.5 kWp	3.0 kWp
Inverter	SMA PV WR 1.8S	SMA Sunny boy SWR 700	SMA Sunny boy SWR 1100	SMA Sunny boy SWR 2500
Start Date	Jun-96	May-01	May-02	Aug-02

Quality tests were carried out on the database. To enable comparison between all the systems a monitoring fraction was done to allow a better understanding of the data sets. It was clear that, the four systems can only be compared after September 2002 when all were operational. The data collected was used to calculate the results presented in graphic mode below.

5. RESULTS AND DISCUSSION

5.1. Systems Performance Analysis

To establish a relation between the systems it was necessary to determine some performance parameters as recommended by the Joint Research Centre, Ispra Establishment [1]. Figure 2 presents a comparison between final yields of the systems.

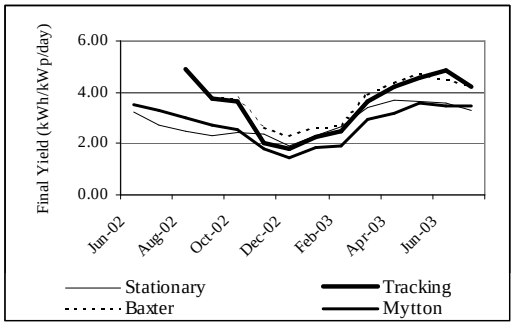

Figure 2 – Mean Monthly Final Yields from June 02 to July 03

The final yield (Y_f) is defined as a ratio that compares the actual output power to the peak nominal solar array power rating at standard test conditions (STC) of 25ºC and an irradiation of 1000 W/m^2. It was calculated using Equation (1):

$$Y_f = \sum_{DAY} \frac{PV_{use}}{P_{nom}} \quad (1)$$

where PV_{use} is the useful energy output in kWh/day and P_{nom} is the nominal peak power output of the system as supplied by the manufacturer.

As expected it may be concluded that as the radiation increased, Y_f also got higher. The tracking system (0.36 kWp) achieved similar values to the Baxter system (3.0 kWp) in the months of higher irradiation, but suffered in winter when occasional rainfall and diffuse radiation are more frequent.

The maximum final yield shown in Figure 2, was 4.89kWh/kWp/day achieved in August 2002 by the tracking system.

The Mytton Lodge (1.5 kWp) system, being placed in a converted quarry, suffered from shadowing especially in winter, thus reducing its output.

The stationary system (1.8 kWp), has normally higher Y_f values than Mytton Lodge. In winter, the Y_f stationary values are only smaller than the ones from Baxter system.

In Figure 3 a comparison of the Performance Ratio (PR) for the plants was made. The performance ratio compares the actual energy output and the theoretical maximum energy output from the system, if it was operating at standard test conditions. This ratio was calculated using Equation (2).

$$PR = \frac{Y_f}{Y_r} \quad (2)$$

where Y_f is the final yield in kWh/kWp/day and Y_r is the reference yield in kWh/kWp/day, numerically equal to the incident radiation on the system in kWh/m^2.

Since losses always existed in converting solar energy into electricity (capture losses) and in the transmission and conversion of electricity within the system (system losses), the value of PR was always less than 1.

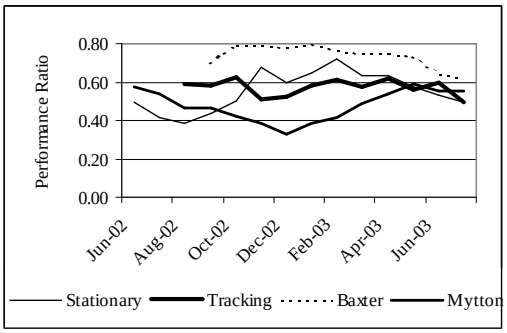

Figure 3 – Mean Monthly Performance Ratios from June 02 to July 03

The Baxter system achieved higher PR and its maximum value was 0.8. In June and July, there was no radiation data for the tracking plane. Even so, the tracking system showed a more stable PR than the other systems with a mean of 0.57. However, these values were

relatively lower due to the higher operating temperatures of the modules as they track the sun. The tracking performance ratio is higher than the stationary in hotter months. It is clear that during winter, most of the tracking inplane radiation was lower than normal and this implies that the tracking mechanism did not respond so well during winter.

The stationary system had a lower annual mean PR with 0.55. The Mytton Lodge PR showed a varying value as time went by, from higher values than the stationary system from June to October 2002 and lower values from November 2002 to June 2003. This is contrary to what one would expect of solar PV modules but again, this is explained for the shadowing on the modules in winter and spring.

The efficiency of the systems were also calculated using Equation (3)

$$\eta = \frac{Output}{Input} = \frac{PV_{use}}{IA^* A} \qquad (3)$$

where PVuse is the useful energy output from the system in kWh and IA is the mean inplane radiation in kWh/m^2 and A is the total area of the modules. In Figure 4 the mean monthly efficiency for the systems is shown.

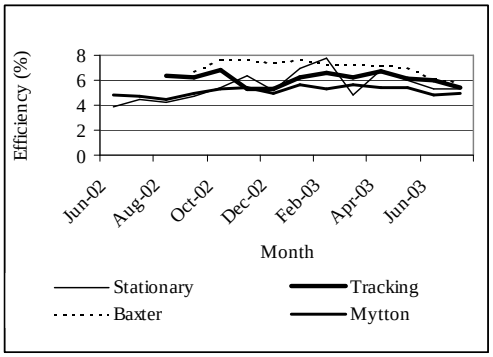

Figure 4 – Mean Efficiency for all systems from June 02 to July 03.

The most efficient system was the Baxter system with a mean of 7.1% and a maximum value of 7.7% occurring in January 2003. The tracking system had a less efficient performance achieving a mean of 6.1% and a peak value of 6.8% in October. The stationary system achieved a mean efficiency of 5.5% but interestingly achieved the same peak value as Baxter in February with 7.7%. The Mytton Lodge system was the only one using mono crystalline silicon cell technology and achieved a mean efficiency of 5.1% reaching a peak of 5.7% in January 2003.

5.2. Grid Connection Analysis

Parameters pertaining to grid performance were also checked. The voltage variation is presented in Figure 5. The fact that the Mytton Lodge had lower grid voltage readings was related to the higher distance from the substation connection point. The stationary and tracking systems had a substation a few meters away and the Baxter system, was placed in an industrial area and has the point of common coupling inside the factory. This explained the higher readings for the Baxter system. The Mytton Lodge showed smaller readings in August 2002, March and April that could be attributed to local power cuts. The low values were due to the averaging of the 15-minute readings when these events occurred.

It is clear that the systems maintained the values in a certain band that dropped slightly by time. This was very likely related to increased demand of electricity with no corresponding increase of substation capacity.

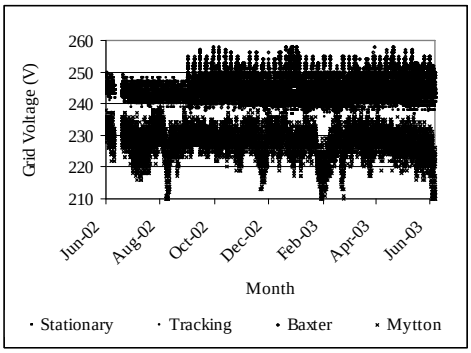

Figure 5 – Grid Voltage from June 02 to July 03.

The variation of the grid frequency was around 49.98, showing a quite stable grid frequency on along-term basis. The values for the stationary system showed a higher band gap. This was related to the fact that this system had a different data logger that only stored the lowest and highest frequency points.

The inverter accepts variation of ± 0.5% of nominal 50Hz grid frequency. If the frequency passes these values or if it changes drastically, the inverter disconnects in 0.2 seconds [3] to prevent islanding. There was no problem in the analysed period.

The grid impedance was also analysed and the results are shown in Figure 6.

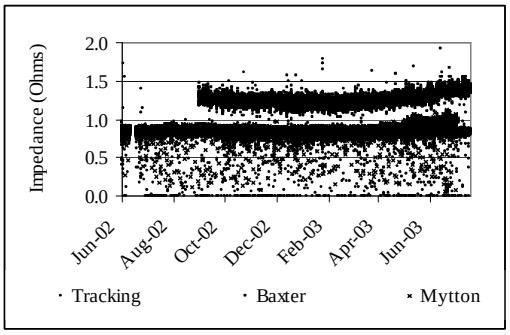

Figure 6 – Impedance for three systems from June 02 to July 03.

It was clear that the Baxter system had higher impedance values, because of the relatively long distance between the inverter and the coupling point to the grid. The Mytton Lodge and Tracking devices showed middle values of grid impedance. Even so, it is possible to see that there are lower peak values for the Mytton Lodge and higher peak values for the tracking system. The data logger for the stationary system did not monitor the grid's impedance.

6. CONCLUSION

The analysis of all the systems showed some interesting results. The performance of the Baxter system was quite good enhancing the investment of the company. On the other hand, the tracking system required more investigation. Nevertheless, previous work done on long-term data has proven the good potential for these systems in the country [4]. A check up of the system needs to be made to increase its potential for winter months.

The stationary system has been providing over 60% of the electricity needs of the IET. Its lower performance was attributed to the fact that the modules have lower efficiency being manufactured in the early 90´s.

The lower results for the Mytton Lodge system were not surprising, since shadowing could not be avoided. The analysis of grid connection showed no problems related to potential islanding, confirming the security of the systems.

The mean performance ratio of the systems ranged from 0.51 to 0.80, and the mean monthly yield was between 2.76 and 3.61 kWh/kWp/day. The mean annual solar radiation in Malta is around 5 kWh/m^2/day. Comparing the results to all the other European projects analysed by the Thermie programme of the European Commission [5], it was clear that Malta's PV systems were within and sometimes surpassed the European range of expected values for PR (0.48 – 0.58) and Y_f (3.3 – 4) kWh/kWp/day.

The systems have saved an equivalent average of 8.4 MWh/annum from the national grid and avoided the emission of 8.03 tonnes/annum of flue gases.

9. REFERENCES

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