EVALUATION OF OUTDOOR PERFORMANCE AND TECHNO-FINANCIAL ANALYSIS OF A STATIONARY HIGH CONCENTRATING PVT SYSTEM

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ABSTRACT: In this paper, we evaluate the outdoor electrical and thermal performance and the techno-financial feasibility of a HCPV/T system. The SunCycle module is a stationary high concentrating PVT (HCPV/T) concept that was developed and patented by the company SunCycle. The SunCycle module uses internal tracking: a prism and parabolic mirror are rotating independently and thereby concentrating the direct light on a small active cell area. A high efficient III-V cell is used to convert the light to electricity, active cooling is used to produce heat. Since it is a stationary system, it can easily be implemented in an urban environment. In 2015 and 2016, the thermal and electrical output of several prototypes of the SunCycle module have been measured outdoors in the Netherlands over a period of multiple months. A maximum electrical efficiency of more than 16% has been measured in the field. Furthermore, a techno-financial model was implemented to calculate the economic feasibility of the SunCycle system for the Netherlands and Jordan. The calculated financial feasibility for Jordan was good, due to a high share of direct irradiance as well as a high price and net metering for electricity. A further increase in efficiency and functionality of the SunCycle module is needed and expected to be realized over the coming years.
Keywords: concentrators, hybrid, performance, thermal performance

1 INTRODUCTION

The company SunCycle developed an innovative high concentrating PVT (HCPV/T) concept that can be applied in the built environment. Since a large share of the energy demand in the built environment in continental Europe consists of heat, the combination of both solar heat and solar electricity production in one roof is interesting.

The SunCycle module uses an internal tracking mechanism. The prism and parabolic mirror are rotating independently and concentrate the direct light on a small active cell area (see Figure 1). The high-efficiency III-V cell is mounted on a cooling block through which a fluid flows and heat is produced. The module produces both electricity and heat. Since the module is stationary it can easily be implemented in the built environment. The modules have a diameter of approximately 50 cm and it is foreseen that a SunCycle system base unit will consist of 20 units. A concentration ratio of 500 x should be reached.

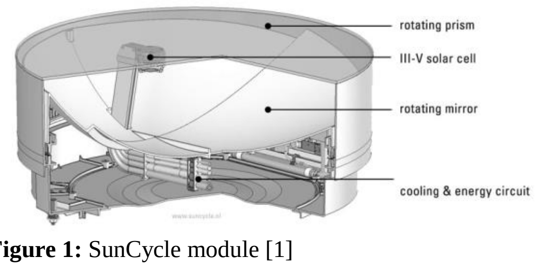

Figure 1: SunCycle module [1]

The work for this paper was carried out in 2015 and 2016. The aim of this paper is to evaluate the electrical and thermal performance of the SunCycle module in an outdoor field test. Furthermore, the goal is to evaluate the techno-financial feasibility for a SunCycle system in the Netherlands and in Jordan.

2 OUTDOOR PERFORMANCE

2.1 Field test set-up

The SolarBEAT facility, see Figure 2, is an outdoor Research & Development infrastructure for innovation on BIPV(T) applications. The facility is a cooperation between SEAC and the Technical University Eindhoven and is located on a large flat south oriented roof with an almost clean horizon. The main use is to measure the performance of BIPV, PVT and solar thermal systems in dependence of several variables (a.o. weather related).

Figure 2: SolarBEAT in 2015

From April 2015 to September 2016 different versions of the SunCycle module have been evaluated (see Figure 3). For every sequence, a single SunCycle module was connected to a pressurized thermal circuit and to a battery set-up. The thermal loop is needed for the required continuous cooling and to determine the thermal response for different inlet fluid temperatures. The fluid inlet temperature could be set between 12 and 80°C. The batteries act as an electrical load.

The following measurement equipment was used:

- Meteorological measurements: DNI measured by a pyrgeometer and ambient temperature. The direct irradiance in the plane of array is calculated by:

G_b = DNI·cos(AOI) [W/m2]

Figure 3: SunCycle module generation 1 (left) and generation 2 (right) on SolarBEAT

- PV performance measurements: Measurements are done at MPP (as determined by the electronics within the module). DC voltage and DC current of both the cell and the module (after DC-DC conversion)
- Thermal performance measurements: input and output temperature of the collector (Pt100, 1/3B) and flow rate (Krohne MID sensor). The heat flow is calculated by:

$$Q_{th} = \rho \cdot c_p \cdot \varphi_v \cdot (T_{out} - T_{in})$$

The thermal performance evaluation was carried out according to the Steady State analysis as described in the norm ISO 9806:2013 [2]. The collector equation for covered collectors is given in the equation:

$$\eta_{th} = \frac{Q_{th}}{A\, G_b} = \eta_0 + a_1 \left(\frac{T_m - T_a}{G_b}\right) + a_2\, G_b \left(\frac{T_m - T_a}{G_b}\right)^2$$

where

η_0 – zero loss efficiency

a_1 – heat loss coefficient [W/m^2 K]

a_2 – wind speed dependence of the heat loss coefficient [Ws/m^{3}K]

And the mean collector liquid temperature is defined by $T_m=(T_{out}+T_{in})/2$ and T_{in} and T_{out} the ingoing and outgoing liquid temperature for the module.

2.2 Field test results

The maximum measured electrical efficiency of the first generation module was 6.7%. This is much lower than the stationary measured efficiency (with a solar simulator) of 15%. The differences can be explained by optical losses in the prism and mirror and a low quality concentration, because of non-optimal tracking.

For the second generation module, many improvements have been implemented with regards to cell design, secondary optics, placement of components, etc. This leads to a much higher reached cell efficiency of maximum 16.3% for the second generation. This is still lower than the stationary efficiency of 19.5 % measured with a solar simulator. Further improvements will be implemented.

The thermal efficiency curve for the SunCycle module generation 1 and 2 that was generated with the steady state model is shown in Figure 4. The zero loss efficiency was 27% for the 1st generation SunCycle module. This improved to 31% for the second generation module. Furthermore, the first thermal loss coefficient reduced from 7.8 to 3.8 W/m^{2}K. The secondary loss coefficient turned out to be not significant. It is expected that the heat losses can be further reduced by better insulation.

There are a large number of measurement points with a low reduced temperature (T_{red}). The large dispersion of values arises due to uncertainties and sensitivity with regards to direct sunlight and electrical performance.

A lot of learning experiences during the field test were made, these will result in a higher quality of modules in the future.

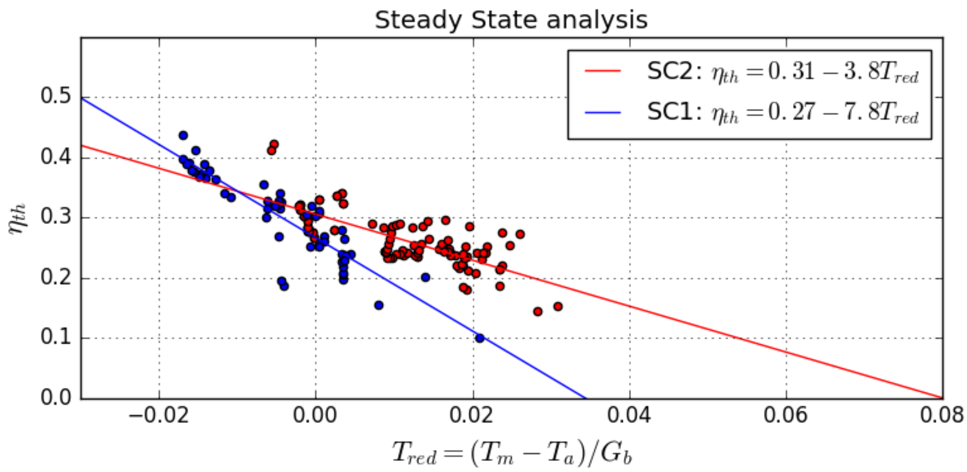

Figure 4: The thermal efficiency curve for the SunCycle module

3 TECHNO-FINANCIAL FEASIBILITY

3.1 Model description

The techno-financial performance of the SunCycle system is important for its commercial success. One of the project goals was to analyze the techno-financial aspects of SunCycle systems. Therefore, a techno-financial model was developed by SEAC in cooperation with Ecofys. The model calculates key financial parameters, like LCOE (levelised cost of electricity), RoI (Return on Investment) and NPV (net present value) from either a consumer or an investor point of view. The model uses technological and financial inputs to calculate key performance indicators. The model has previously been used for analyzing business models for BIPV systems. Since the SunCycle module is a HCPV/T module that produces both power and heat, the model was extended.

A system of 20 modules (approximately 4 m^2), including installation and other system components (inverter, storage, pump, etc.) was used as a reference. The yield was estimated based on the current technology and the expected efficiency increase in 2018 and 2020. The scenarios for efficiency increase are very positive; the yield almost doubles in 2018 and increases with a further 35% in 2020. The increase in efficiency is caused by a low current efficiency of DC-DC and DC-AC conversion (both 80%) and by expected increase in module efficiency.

Like the Netherlands, Jordan currently has a net metering practice. The electricity price depends on electricity usage. We took three scenario's into account: €0.11/kWh, 0.203€/kWh en 0.34€/kWh.

3.2 Results

The case study investigated the financial attractiveness of the ownership of a 20 module HCPV/T system of SunCycle. Using a base case, including future values for yield and costs, and varying critical parameters, several scenarios are made, resulting in the net present value (NPV) and levelized cost of energy (LCoE). The techno-financial analysis is very positive for the situation in Jordan and not positive for the Netherlands. A summary of the results is shown in Figure 5.

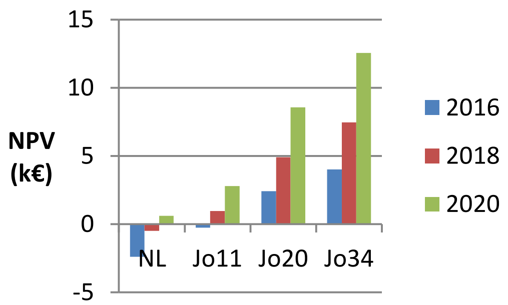

Figure 5: The Net Present Value (NPV) for Netherlands and Jordan, with three different electricity pricing scenarios, for 2016, 2018 and 2020. Jo11 refers to an electricity price of 0.11€/kWh, Jo20 to 0.2 €/kWh and Jo34 to 0.34 €/kWh.

One conclusion is that in the Netherlands the base cases for 2016 and 2018 are not financially beneficial for the user within a reasonable number of years. The initial investment cannot be earned back from the revenue of the yield if a SunCycle system of 20 units is bought and installed in the Netherlands. However, the base case scenarios of 2020 results in a positive NPV, because the yield is expected to increase rapidly and the costs to decrease. One of the reasons for these results is that there is not much direct irradiation in the Netherlands. In Jordan, with almost three times as much direct irradiation, the situation is a lot brighter. In Jordan the SunCycle system has a very positive NPV for all scenarios from 2018 onwards and for most cases in 2016 as well. The payback time of the system is very low in 2020 with 3 to 7 years. The NPV in Jordan is mainly sensitive to the used discount rate and the gas and electricity prices.

3.3 Discussion

The original plan was to use the outcome of the field test for the yield estimation of the techno-financial model. Due to delays, this was not possible. Therefore, estimates have been used. The electrical efficiency of 20% is quite optimistic; it has been measured at certain moments, however, not for longer time frames. Also the improvements in efficiency are ambitious. The yields and costs as forecasted by SunCycle could not be validated, due to a very early market positions.

4 CONCLUSIONS

A summary of the major conclusions follows:

Different versions of the SunCycle module have been measured in 2015 and 2016 outdoors. A maximum operating module efficiency of 16.3 % before DC-DC conversion has been measured. Much knowledge for further increasing the module performance has been generated.

An early techno-financial feasibility study has been carried out for a system with 20 SunCycle modules. A positive outlook exists for Jordan, a country with a high direct irradiance.

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