ENHANCED INTEGRATED SOLAR HOME SYSTEM

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ABSTRACT: To date, many traditional Solar Home Systems (SHS) have consisted of separate components requiring assembly by trained individuals in the field. While this cannot be secured, many SHSs in remote areas have not fulfilled their expected lifecycles or have not functioned at all. The Integrated Solar Home System (I-SHS) offers a solution: All components such as PV module, charge controller, inverter and wiring, but also support structure and foundation, are integrated and pre-assembled by the manufacturer. This eases installation and reduces costs and failures. Additionally, through the integration of a water tank that serves as a cooling unit as well as the system foundation, a significant reduction of operating cell temperature was achieved, increasing electrical yield by 9–12%.
Further improvements have been implemented recently at the Enhanced I-SHS (EI-SHS): The water volume of the tank above the PV module has been increased, thus further reducing operating cell temperature. The power condition units and the storage are placed more in the center of the device, allowing a better water circulation, resulting in less stratification and a better cooling. In the future the EI-SHS will be equipped with an electricity counting device and a payment unit to allow refinance of the system by selling PV electricity. A recently developed satellite monitoring system will be integrated, allowing remote energy metering and billing.
Keywords: Cost reduction; Solar home system; Battery storage and control.

1 INTRODUCTION

1.1 Effect of temperature

The electrical power generation of a solar cell depends on its operation temperature. While the short circuit current (I_{sc}) increases slightly with increasing temperature, the open circuit voltage (V_{oc}) decreases significantly (about -2.3mV for each K) with increasing temperature, leading to a reduction of electrical power and yield of -0.4%/K to -0.5%/K for mono- and multi-crystalline silicon solar cells which are used in most SHS applications.

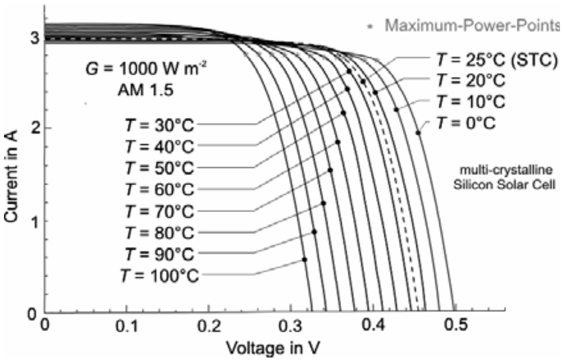

Fig. 1. I-V characteristics for different temperatures of a typical multi-crystalline silicon solar cell.

While efficiency and electrical yield is decreasing with increasing operation temperature, the idea to keep the system at low temperatures is quite evident.

Operation temperatures were kept at low levels by mounting the module on a water-filled tank. Another efficient cooling method using a flowing film of water is presented in [5], but the method described here allows for an effective reduction of operating cell temperatures without spending any energy for refrigeration. The water virtually soaks up the heat flow generated by the module. Due to the high thermal capacity of the incorporated water the temperature increases gradually. The principle was proven and validated with different prototypes in Europe and in Africa built over previous years [1–3].

1.3 Latent heat storage

The first cooling device which followed the ‘‘cooling by an extended heat capacity’’ concept was built in 1992. The tank was integrated into the original framing of a M55 PV module by Siemens (volume: 12 l), so it could be used with conventional mounting. This prototype provided a 2.6% increase in daily electrical energy yield. Subsequent tests, which utilized latent heat storage material (sodium sulphate), showed significantly better results but caused severe corrosion at the terminals.

1.4 TEPVIS—Thermal Enhanced PV module with an Integrated Standing

The second prototype built in 1994 had a much larger tank which served also as the module’s foundation, stand and mounting structure (see Fig. 3). It was tested with another M55 (also called SM55) module which showed a significant temperature reduction (see Fig 2) and resulted in a gain of electrical energy yield of 12%.

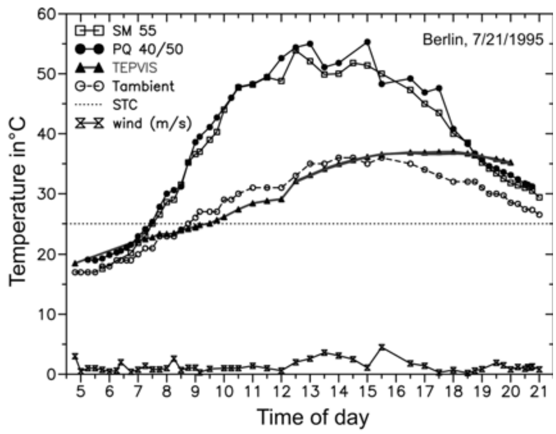

Fig. 2. Temperatures of TEPVIS in comparison to conventional PV modules (SM55, PQ40/50) in Berlin, Germany.

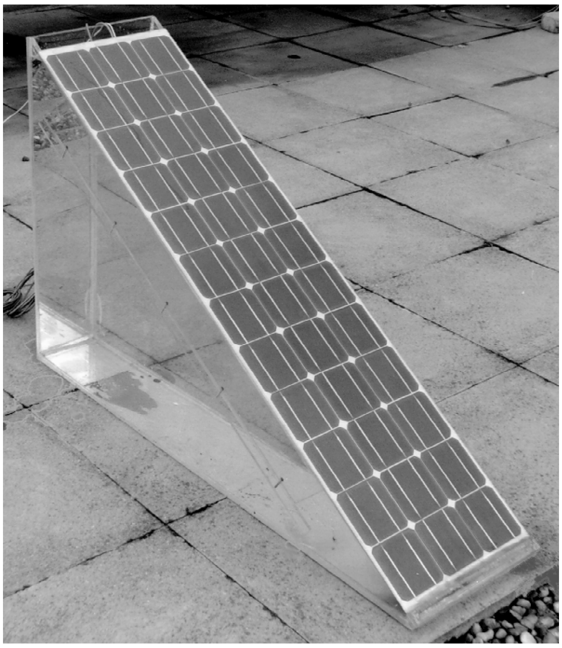

Fig. 3. Thermal Enhanced PV with Integrated Standing (TEPVIS): proof-of-principle prototype, showing a gain in electrical yield of 11.6% (Berlin, Germany, 1995)

2 I-SHS—INTEGRATED SOLAR HOME SYSTEM

In addition to reducing operating cell temperatures of the PV module, the I-SHS includes all components such as battery, charge controller, inverter and wiring of a SHS in the container-tank, thereby reducing the ‘‘Balance of system costs’’ (BOS).

Fig. 4 shows the basic layout of the system built and tested in 2002: The PV generator consists of two parallel-connected frameless 30 W_p modules. Located in the foundation structure are a maintenance-free lead acid battery (12 V, 105 Ah) and a 200 W sine inverter (115 V 60 Hz) with an integrated charge controller (6 A). A water tank cools all components. The output leads to a regular AC plug.

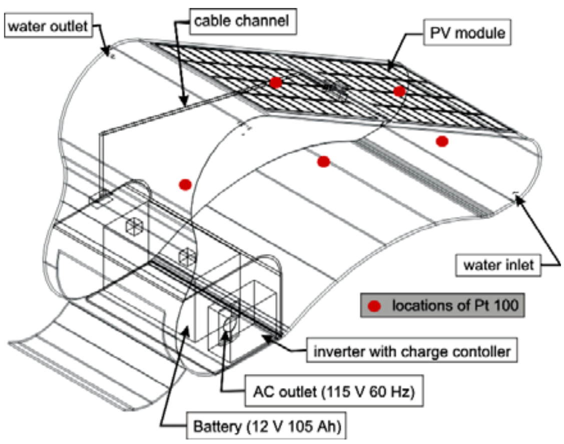

Fig. 4. Structure and components of the first Integrated Solar Home System (I-SHS).

Fig. 5. The first I-SHS prototype during tests in Copacabana, Rio de Janeiro, Brazil in 2002. Design by ‘‘Escola de Belas Artes’’, UFRJ, Rio de Janeiro (modified by Fabian Ochs).

That first prototype is 1.37 m long, 0.76 m high, 0.5 m deep, and has a volume of 0.3 m^3 (see Fig. 5). A module elevation angle of 30° was chosen to achieve an optimal year round yield in most parts of Brazil. The tank has a volume of 300 l, and weights more than 300 kg when full (including PV modules, charge controller and inverter

The tank acts as an efficient cooler for the PV modules. The aluminum back of the frameless PV modules allows for good heat transfer to water stored in the tank. The water, with its high specific heat and huge thermal capacity, limits solar cell temperatures to a range in proximity to that of ambient temperatures (see Fig. 6).

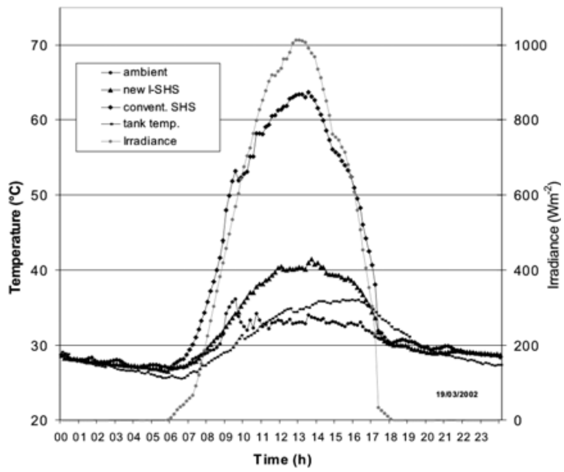

Fig. 6. Temperature measurements of the I-SHS during a clear day (see ‘‘Irradiance’’): The lower module temperature (new I-SHS) and water temperature in the upper part of the container (tank temp.), in comparison to a conventional SHS and ambient temperature.

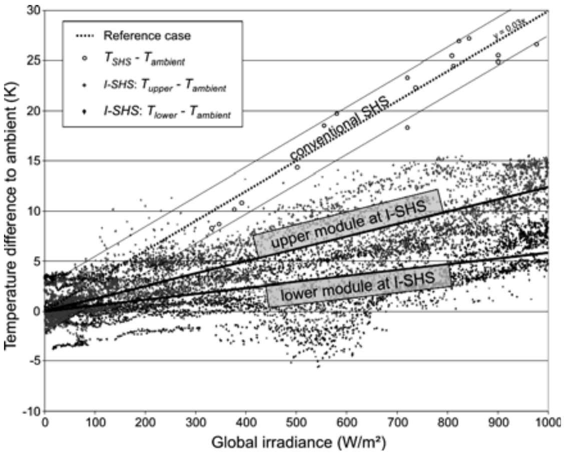

Fig. 7. Differences between module temperature and ambient temperature in comparison to the reference case (conventional SHS) plotted as a function of irradiance.

In previous experiments, a reduction in cell temperatures during operating time increases electrical yield by up to 12% [1–3], see also Section 1 above. Due to the stratification observed, the first I-SHS showed just a 9% gain [6]. Forcing circulation in the tank would certainly result in higher electrical yields, on the other hand, stratification serves very well for an optional thermal use of the system. The hot water generated is sufficient for the consumption of a small household in Brazil. The upper module can also be replaced by a thermal absorber and would boost hot water generation.

3 BALANCE OF SYSTEM COSTS (BOS)

Since the foundation, support structure and mounting equipment are no longer required, significant reductions in installation costs and ‘‘turn-key’’ system costs are achieved. Together with improved aspects of maintenance and higher energy yields, PV electricity is becoming more available. Once the I-SHS has been placed at an appropriate site, it has just to be filled with water and is immediately ready to supply power to any AC device from its standard plug. The weight of the tank-container, without inverter and battery, is about 8 kg, making transportation easy. When filled with water the container has a weight of more than 300 kg, thus making the system stable enough to withstand any storm without additional fixings.

4 ENHANCED I-SHS

Further improvements have been implemented recently: The water volume of the tank above the PV module has been increased, allowing additional storage of hot water in the upper part, thus further reducing operating cell temperature of the PV module at the lower and central part of the device, thus enabling the use of a module with a reduced number of solar cells (e.g. 32 or 33 instead of 36 cells). The power condition units and the storage are placed more in the center of the device, allowing a better circulation via the thermo-siphon effect, resulting in less stratification and a better cooling, even for the batteries (see Fig. 8).

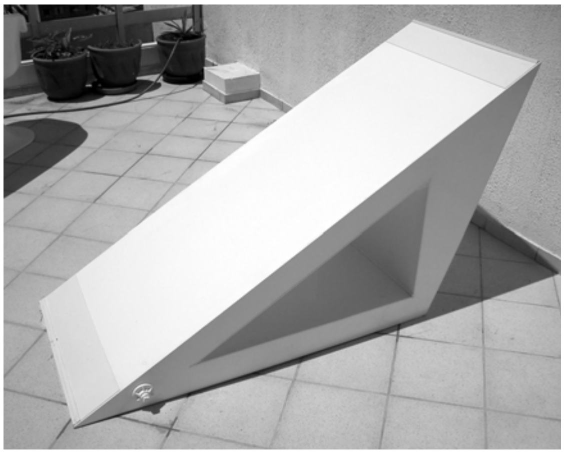

Fig. 8. Latest enhanced I-SHS prototype with increased hot water storage capabilities in the upper part, enhanced water circulation, and a cooled triangular space for battery, inverter, and charge controller (Rio de Janeiro, Brazil, 2003).

In the future the enhanced I-SHS will be equipped with an electricity metering device and a payment unit to enable refinance of the system (or at the least battery exchange) by selling the PV electricity generated. A recently developed satellite monitoring system will be integrated [7], allowing remote energy metering and billing, eventually using the solar cells as an antenna for data transmission [8].

5 CONCLUSION

Once placed at an appropriate site the enhanced I-SHS is immediately able to supply small AC loads (illumination, fan or small ventilator, radio, TV, video recorder, CD player, computer etc.). Additionally it is capable of supplying the hot water needed for a small household. Several systems can be combined to fulfill higher power needs without a redesign of the system. Without having higher costs than conventional SHSs, and featuring favorable BOS and the generation of more energy, the enhanced I-SHS is an efficient means to successfully electrify remote areas, bur also as a compact flat-roof PV device for urban areas.

Benefits of an enhanced I-SHS:

- ease of installation,
- significant reduction of system costs,
- increased efficiency via low cell temperature operation,
- increased reliability via pre-manufactured and pre-tested units,
- standard AC output (Plug & Play) and
- optional use of warm water as a by-product.

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