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AN INTEGRATED SOLAR HOME SYSTEM - HISTORY

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ABSTRACT

To date, many traditional Solar Home Systems (SHS) have consisted of separate components which required assembly by trained individuals and were also more susceptible to failure and maintenance. As a result, many SHSs in remote areas have not fulfilled their expected lifecycles or simply have not functioned at all. Thankfully, a solution to these problems has arrived – the newly developed Integrated Solar Home System (I-SHS). Within this new system all components such as the support structure, foundation, PV modules, charge controller, DC-AC converter and wiring are pre-assembled by the manufacturer. This eases installation and maintenance resulting in a reduction of cost and failure. Additionally, electrical yield was increased by 9% by a significant reduction of operating cell temperature. This was achieved by an integrated water tank, serving as a cooling unit and also providing the system's foundation. This measure is neither expensive nor energy intensive, improves output of the system in an unproblematic way, and also allows use of the heated water.

1. TEMPERATURE DEPENDENCE OF PV OUTPUT

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 -2.3 mV for each K) with increasing temperature, leading to an electrical yield reduction of -0.4 %/K to -0.5 %/K for mono- and multi-crystalline Silicon solar cells which are used in most SHS applications. Figure 3 shows the *I-V*-characteristics for a typical multi-crystalline Silicon solar cell at different temperatures together with the operation points for maximum power generation

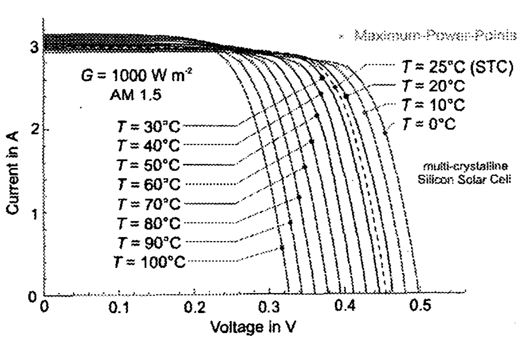

Fig. 3 *I-V* characteristics for different temperatures of a typical multi-crystalline Silicon solar cell.

2. TEMPERATURE REDUCTION

While efficiency and electrical yield is decreasing with increasing operation temperature, the idea to keep the system at low temperatures is quite evident. The energy consumption of an active cooling system would not be compensated by the gain in increased energy generation, at least for small systems. Operation temperatures were kept at low levels by mounting the module on a water-filled tank. This 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 [2,3,4].

2.1 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 SSI (volume: 12 liters) 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.

2.2 TEPVIS – Thermal Enhanced PV module with 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. It was tested with a M55 which showed a significant temperature reduction (see Fig. 2) which resulted in a gain of electrical energy yield of 12%.

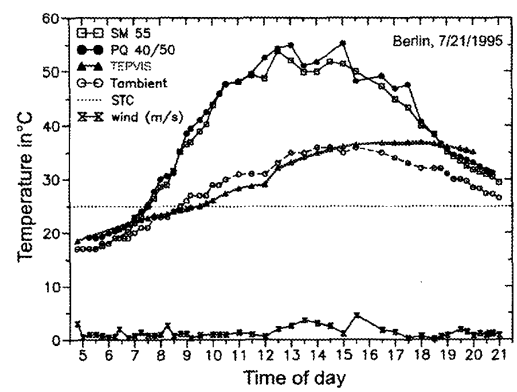

Fig. 2 Temperatures of TEPVIS in comparison to conventional modules (SM 55, PQ 40/50) in Berlin.

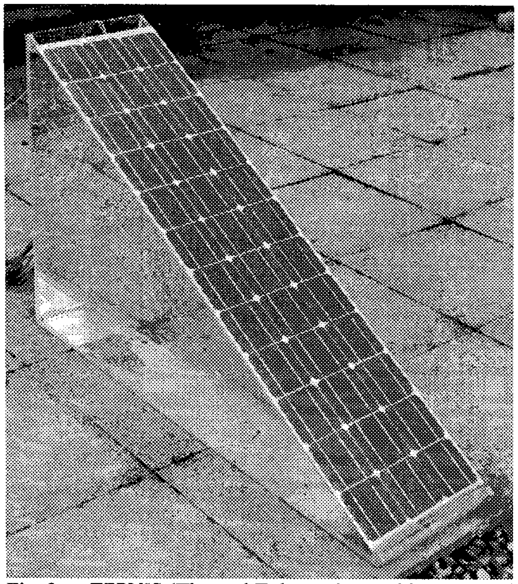

Fig. 3 TEPVIS (**T**hermal **E**nhanced **PV** with **I**ntegrated **S**tanding) - proof-of-principle prototype showing a gain in electrical yield of 11.6% (Berlin, 1995).

TEPVIS was also tested using multi-crystalline PQ 10/40 modules in Bulawayo, Zimbabwe (see Figures 4, 5, 6) which proved a gain of 9.5%. The gain in Zimbabwe was lower due to reduced water circulation and more stratification (the upper part of the tank is considerably warmer than the lower one). The inclination of the module plane in Zimbabwe was much lower reducing the thermo-siphon effect. Also the device in Berlin was equipped with an additional plate inside the tank, in parallel to the module, forming a kind of chimney and thus enhancing circulation ("Onneken's seperator").

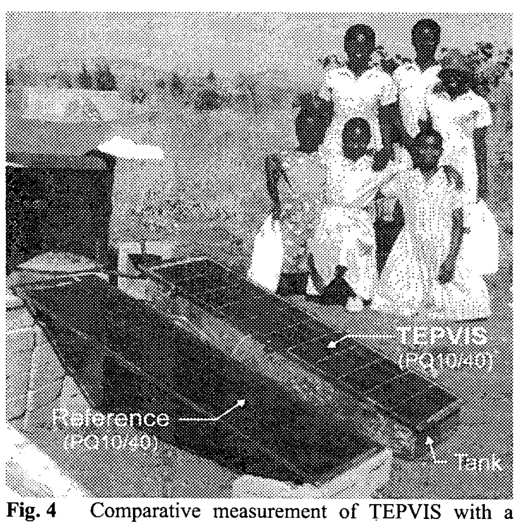

Fig. 4 Comparative measurement of TEPVIS with a standard reference PV module in 1995 in Zimbabwe.

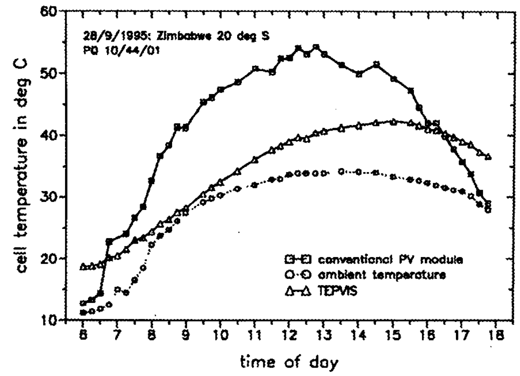

Fig. 5 Measurements of temperatures during a clear in Zimbabwe: TEPVIS in comparison to a conventional module (PQ 40/50).

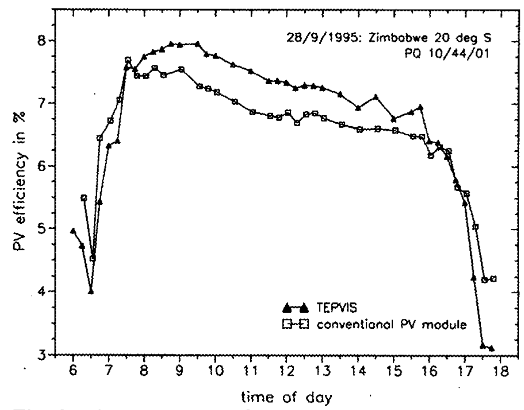

Fig. 6 Measurements of PV conversion efficiencies of TEPVIS in comparison to a conventional module (PQ 40/50) during a clear day in Zimbabwe.

To eliminate possible measurement errors which may have been caused by the differing electrical properties of the systems, all modules were interchanged and retested.

3. I-SHS – INTEGRATED SOLAR HOME SYSTEM

Beside 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, thus reducing the "Balance of System costs" (BOS). Figure 7 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. The prototype is 1.37 m long, 0.76 m high and 0.5 m deep. A module elevation angle of 30° was chosen to achieve a good yield even in winter in most parts of Brazil. The tank has a volume of 300 liters, which results in a weight of more than 300 kg, when full.

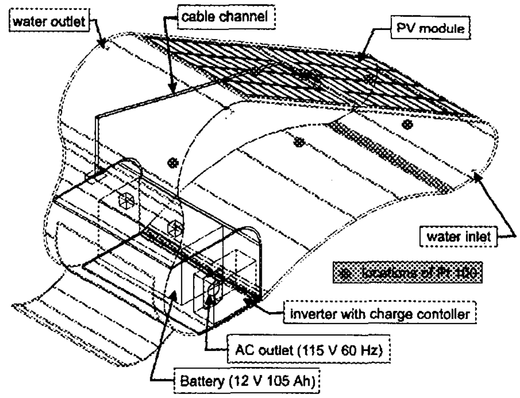

Fig. 7 Structure and components of the Integrated Solar Home System (I-SHS).

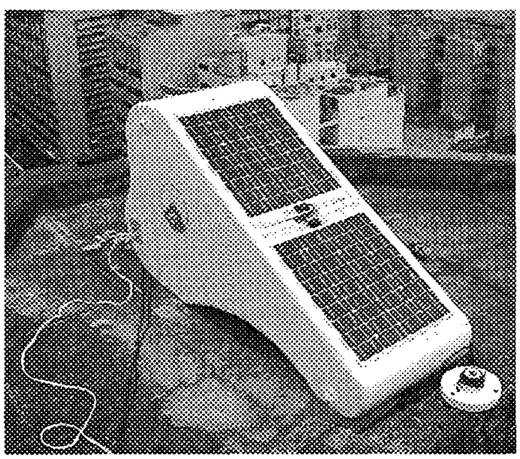

Fig. 8 The I-SHS prototype during tests in Copacabana, Rio de Janeiro, Brazil. Design by "Escola de Belas Artes", UFRJ, Rio de Janeiro.

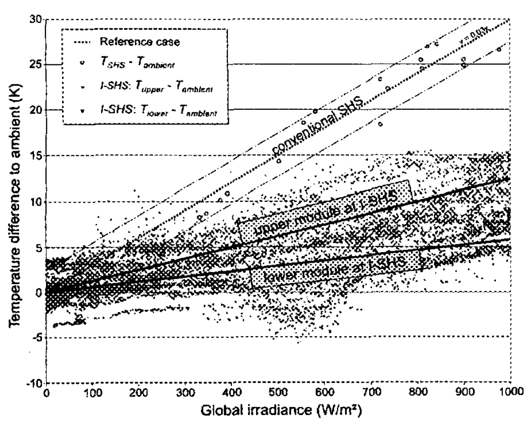

Fig. 9 Differences between module temperature and ambient temperature in comparison to the reference case (conventional SHS) plotted as a function of irradiance.

The increase of cell temperature relative to ambient temperature was measured for several days in Rio during March 2002 and is shown in Figure 8 as a function of irradiance in comparison to the equivalent values for a conventional SHS [5,7,8]. Despite a relatively wide spread in values, mainly due to wind speed variations, the following linear approximations can be extracted:

$$T_{comv.\ SHS} - T_{ambient} = 0.03 \cdot G\,(\mathrm{W/m^2})^{-1}\,\mathrm{K} \quad (1)$$

$$T_{I\text{-}SHS\ upper} - T_{ambient} = 0.012 \cdot G\,(\mathrm{W/m^2})^{-1}\,\mathrm{K} \quad (2)$$

$$T_{I\text{-}SHS\ lower} - T_{ambient} = 0.0058 \cdot G\,(\mathrm{W/m^2})^{-1}\,\mathrm{K} \quad (3)$$

G stands for global irradiance, T_{SHS} for module operation temperature of a conventional SHS ("Reference Case") as measured [7,8] or given in literature [5,6]. T_{upper} stands for the temperature of the upper module and T_{lower} for the lower module in the I-SHS. All temperatures are given in Kelvin (K) or degree Celsius (°C).

In previous experiments, a reduction in cell temperatures during operating time increases electrical yield by up to 12% [3, 4], see also "2.4 History". Due to the stratification observed, the I-SHS showed just a 9% gain. 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. Additionally, 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.

4. MANUFACTURING OF AN I-SHS

For testing purposes a single prototype was manufactured. Mass production of the I-SHSs (e.g. by PP or PE) would be fast and inexpensive with large scale production costs at less than 50 €. Material problems related to UV stability and the drying of the plastic seem to be solved - manufacturers of similar tanks (used as floating docks for boats) give guarantees of 10 years.

4.1 Prototype

The prototype's form is shaped from a block of expanded polystyrene (EPS). Subsequently the container-tank, consisting of six parts, was laminated using a fiber glass and epoxy resin. To allow for modifications the modules are mounted in a detachable fashion. A cable channel through the tank was installed to simplify maintenance. Material costs for the prototype have been 420 € and are listed in Table I.

Table I. Costs of materials for the prototype structure.

Materials	Number, value	Unit	Cost (€)	Total cost (€)
Styrofoam	1	m³	45	45
Fiber glass	30	m	5	150
Epoxy resin	5	kg	30	150
Glass bubbles	1	litres	25	25
Other	1		50	50
All				420

Construction time for the prototype was less than a week. An optional non-exchangeable integration of the PV modules within the tank-container would provide improved performance by better heat transfer and would reduce construction time.

4.2 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 seven 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.

5. CONCLUSION

Once placed at an appropriate site the I-SHS is immediately ready to supply small AC loads (lightning, air-fan, radio 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 I-SHS is an efficient means to successfully electrify remote areas.

Benefits of an 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 and Play")
- Optional use of hot water as a by-product.

6. OUTLOOK

The I-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 [9], eventually using the solar cells as an antenna for data transmission [10].

7. ACKNOWLEDGEMENTS

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