Solar Energy Systems – Selected Applications

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Abstract

Only a whole systems approach incorporating distributed generation, storage and advanced control can contribute to decarbonisation, security of supply and affordability of energy.

Even among trained engineers often detailed knowledge about the competitiveness of solar energy is not fully developed. Using selected examples from the fields of solar thermal energy use and solar electric systems the multifunctional features are outlined. In combination with different storage technologies attractive technical solutions can be identified which are also very economic.

Kurzfassung

Um die Energieeinsatzziele der EU für 2050 zu erreichen, gilt es eine neue Energiemarktordnung zu realisieren. Der Schwerpunkt liegt in diesem Beitrag auf dem Bereich der Sonnenenergienutzung. Diese kann vorteilhaft zur Deckung des hohen Bedarfs an Niedertemperaturwärme in Nordeuropa eingesetzt werden, sowohl für Heizungen als auch die Warmwasserversorgung von Gebäuden. Die Energienachfrage kann erheblich reduziert werden, wenn bei Hausneubau oder Renovierung auf eine hohe Dichtheit der Gebäudehülle geachtet wird. Das hat zur Folge, dass Maßnahmen zur kontrollierten Lüftung der Wohneinheiten notwendig werden. Ein Großteil der Abluftwärme kann rückgewonnen werden, wobei die Gesamtlüfterleistung bei etwa 50 W liegen sollte, um nicht den elektrischen Energieeinsatz zu stark zu erhöhen. Ein gutes Beispiel ist eine Wohnanlage in Hutton Rise/Sunderland/UK, bei der ein Kessel zur Beheizung von acht luftdicht gebauten Wohneinheiten ausreicht, anstelle der sonst notwendigen acht Heizkessel.

Eine weitere Option ist die Kraftwärmekopplung (KWK) bei der Nahversorgung von Gebäuden mit Niedertemperaturwärme und elektrischer Energie, da der Nutzungsgrad bei neuen Anlagen im Bereich von 95 % liegt. Ein Nahwärmeversorgungssystem lässt sich jedoch auch als Kombination von KWK und großem Kollektorfeld in Verknüpfung mit einer Wärmepumpe realisieren. Ausgeführte Anlagen im In- und Ausland belegen diesen Primärenergie einsparenden Sachverhalt.

Verschiedene wärmegestützte Anlagen zur Raumklimatisierung stehen heute in Verknüpfung mit Absorptionskältemaschinen zur Verfügung. Die Verdichtung des Kältemittels wird in gelöster, flüssiger Form in einem Sorptionsmittel durchgeführt. Typische Kälte-/Sorptionsmittel Kombinationen sind H_20/LiBr und NH_3/H_20. Für die Gebäudeklimatisierung wird – wegen der besseren Energieeffizienz – das H_20/LiBr – Paar oft eingesetzt.

Die erheblichen Kostenreduktionen im Bereich der Silizium-Solarzellen-Technologie haben neue Anwendungsbereiche für solarelektrische Systeme erschlossen. Zusätzlich zu den Großanlagen im MW-Leistungssegment, die der Netzeinspeisung dienen, erhält die gebäudeintegrierte Photovoltaik (BIPV) verstärkt Bedeutung. Die von den – häufig farbigen – Modulen bereitgestellte Energie wird im Gebäude direkt eingesetzt und ggf. gespeichert und nur zum geringen Teil ins elektrische Energieversorgungsnetz eingespeist. Ein weiteres Anwendungsfeld sind die Ladestationen für die Elektromobilität, die zum großen Teil aus PV-Anlagen gespeist werden.

1 Introduction

According to a study of the EU the energy supply in the year 2050 could look like:

Solar power	40 %
Biomass/Waste	30 %
Wind power	15 %
Hydro power	10 %
Fossil fuel	5 %

The energy gap up to 2050 can be bridged when beside a balanced energy mix also energy efficiency is improved for all the energy conversion devices. In addition peripheral technologies such as sensors and power electronic switches should become more reliable.

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2 Solar Thermal Systems

Although the focus is on active systems a large energy saving contribution is related to passive systems. The building sector is very energy intensive. Commercial business – and private-buildings account for one third of the worldwide energy consumption.

This fact creates a heavy contribution to the CO_2 emissions and therefore existing buildings should be improved and new buildings should be characterized by smart design and clever construction by using novel or improved building material. This will result in zero-energy houses or even energy-plus houses.

Innovative system design should include a monitoring system, so that efficiency can be analyzed in a permanent fashion and appropriate improvements and/or adjustment made where necessary. A solar-responsive design provides the tool for effective passive solar heating, shading and day lighting. Solar thermal systems should not just be added to the building – the trend is towards building integration [1].

If the LEED award (Leadership in Energy and Environmental Design) is considered, all the relevant environmental aspects of the building are taken into account. In Germany about 2 million solar thermal systems are installed – however, the market developments in recent years were modest. It is hoped that new legislation, novel media and new education platforms help to improve the situation [2, 3]. The number of energy self-sufficient houses is increasing, however, on a low level [4].

Air-tightness and avoided thermal bridges bring also a contribution to energy saving. A good example is the Hutton Rise housing development in Sunderland/UK. Eight airtight houses can be supplied with heat by just one boiler. Under standard conditions eight boilers had to be installed (**Fig. 1**). Controlled domestic ventilation systems with heat recovery reduce ventilation heat losses. It is possible to achieve 80 % recovery rates. Higher rates increase the electricity consumption by the ventilation units. As a guideline: 50 W total power for each housing unit should be aimed at.

Fig. 1 Example of airtight houses
(Source: Engineering Technology, Feb. 2014)

District heating is also an option for thermal collectors in combination with heat pumps. With a flat plate collector area of 8000 m² an energy yield of 4 GWh/a can be realized (**Fig. 2**). In a specific example for Germany the collector cost were 200 €/m².

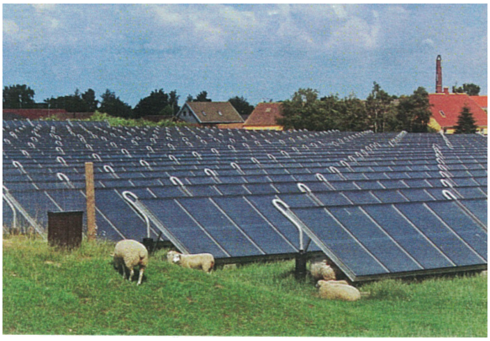

Fig. 2 Example of district heating in Germany
(Source: Sonne, Wärme, Wind)

2.1 Solar cooling

Absorption cooling machines driven by thermal energy have found a large number of applications, as these machines use solar heat from flat plate collectors or vacuum tube collectors.

The performance of a cooling process is characterized by the “energy efficiency ratio”: EER. This is the ratio of cooling power over motive power. Compression cooling machines typically have an EER = 3 … 4.

Thermal cooling machines, e. g. absorption machines, use beside thermal energy also electricity for the operation of the solvent pump. Therefore often two EER parameters characterize a absorption-cooling machine.

Typical working fluid combinations are $H_2O/LiBr$ and NH_3/H_2O. For the climatization of buildings mainly a $H_2O/LiBr$ combination is used. In this case a driving temperature of 55 °C up to 105 °C is needed. Then a temperature of 6 to 16 °C for the cold water can be achieved. Only about 120 W pump power is needed for such a 10 kW_{cold} process.

In the case of a refrigerating compressor electric power of 3.4 kW is required to achieve 10 kW_{cold} power. By practicing absorption cooling with solar thermal power a big saving on the electricity bill can be observed. Absorption cooling systems are available in the power range from 2.5 kW up to 1.5 MW_{cold} power.

For such a large thermal power also a large collector field is needed, which is in the range of 3900 m².

With the rapid decline of the specific cost in €/kWp in the field of photovoltaics it soon might be feasible to operate refrigerating compressors with solar electricity in the near future.

For the evaluation of solar thermal cooling systems guidelines are needed. Within IEA-SHC programme in Task 48 quality assurance and support measures for solar cooling systems are being developed.

3 Solar Electric Systems

Reliability and quality improvements in solid state physics resulted in 25–30 years of operation time for solar electric systems. The extended life time is essential for the economic operation on building integrated photovoltaics (BIPV) arrangements.

Civil engineers, architects and electrical engineers working together can erect buildings that fulfill the LEED standard. Energy efficient buildings are essential for the future of mankind [5].

The multifunctions of photovoltaics are impressive:

- Energy conversion
- Weather protection
- Noise reduction
- Heat insulation
- Sunshade
- Partition (modesty panel)
- Architectural element
- Power dressing.

Some researchers work on concentrator cells. In this case often the selected material is III–V semiconductor material. The concentration factor can range from 2.5 to 500. Mirrors or lenses (Fresnel-type) are in operation. An efficiency of 35 % for a concentration factor of 500 has been achieved.

Beside the work done on mono- and polycrystalline cells also thin film and tandem cells are under investigation. A newcomer is the Perovskite-cell, a novel thin film development. The efficiency of this type of cell is quite promising.

There are still developments to improve the performance of mono- and polycrystalline cells by adding a passivation layer on the cell backside in order to reflect light of longer wave-length. This results in an increase of the cell current and efficiency. That approach of "passivated emitter rear contact" lead to the new name: PERC-cell.

Only recently more work is done on hybrid systems. This is a combination of a photovoltaic module and a solar thermal absorber. This work is triggered by the EU legislation concerning net zero energy building.

Worldwide plans exist to increase the photovoltaic energy contribution. For example, the government in India is on its way to enlarge the pv-power from 3 GW (2015) to 100 GW in 2022.

Large-scale pv plants comprise about 45 % of the global cumulative installations. The two largest capacities have an installed power of 550 MWp. On rank three is a Chinese plant with a power of 480 MWp. As the cost of the modules represent about 52 % of the total cost of a pv plant, it is essential to monitor this element in order to have a profitable pv plant.

3.1 Monitoring of large pv generators

As the power level for the photovoltaic generator increases, there is a demand for quality packages for bankability. Special characteristics of a module have to be examined in detail to ensure the maximum energy yield over many years. The behavior under weak light conditions is one of them. Two modules might have the same efficiency at 1000 W/m² of insolation. However, an elevated efficiency at lower levels of insolation offers a much higher energy yield of 890 kWh/kW$_p$ compared to 865 kWh/kW$_p$ for a specific location (**Fig. 3**). Failure of pv-modules can be classified according to the time of their occurrence: infant failure, midlife failure and wear-out failure.

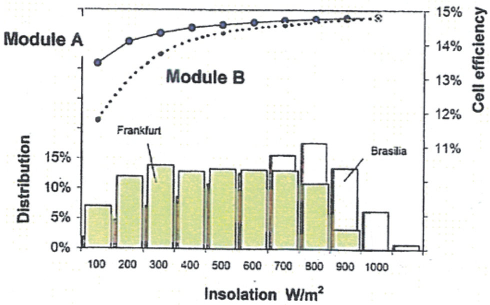

Fig. 3 Low irradiance performance of pv module

Typical infant-failures are:

- Loose frame
- Glass breakage
- Open string interconnect
- Contract failure in junction box.

Midlife-failures might be:

- Diode failure
- Cell interconnect breakage
- Potential induced degradation (PID)
- EVA discolouring.

About 2 % of the modules in a large pv-generator fail after 11–12 years of operation and do not meet the manufacturer's warranty. Quality inspections are vital to detect and diagnose infant- and midlife-failures. For warranty claiming issues it is important to identify the responsible company e. g. module manufacturer, delivery company or company in charge of the installation [9].

In order to be competitive a manufacturer might use cheap EVA for the encapsulation and that may be prone to PID (potential induced degradation). With the intention to minimize the DC losses of a large pv-generator the number of modules per string increases and a higher DC voltage characterizes the system that is also a prerequisite for the PID effect [10].

Typically 1000 V on the DC side are selected. However, there are plans to move to a voltage of 1500 V$_{DC}$. [14].

Under normal operating conditions the irradiance generates electricity and heat in pv-modules and the temperature distribution at the module is homogenous as indicated with **Fig. 4** (upper part).

Inhomogenous temperatures indicate failures. The two dimensional temperature distribution can be measured with an infrared-camera. Infrared (IR) imaging or thermography is a powerful non-destructive and contactless measurement technique. IR measurements should always be performed under steady state conditions. IR thermography is done by means of special IR-cameras, either hand held or airborne. Unmanned aircraft systems (UAS) can be bought on the market as a package.

The flyover parameters such as height, speed, optics change from PV plant to PV plant and therefore this is an interesting research topic to minimize the specific monitoring cost in €/MW$_p$.

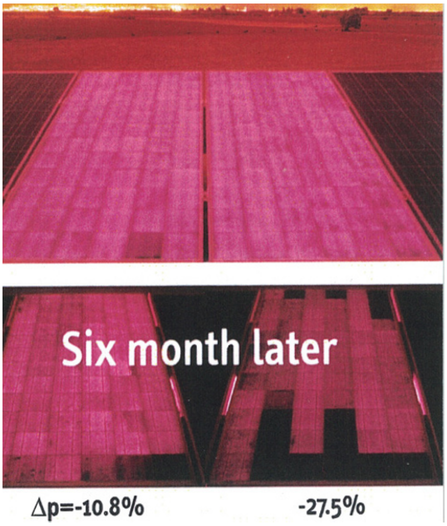

Fig. 4 Degradation of PV modules due to PID resulting in loss of power (Source: PI-Berlin)

PID-affected modules can be detected when the flight height is about 10 m and a good IR-camera (Optris P/450) is used. Wind speed should be below 25 km/h and the level of irradiance at 600 W/m² to achieve a good resolution of 5 x 5 pixel/cell.

A complementary technology to identify faulty modules is electroluminescence-imaging (EL).

3.2 Bifacial module application

A bifacial module has the physical ability to produce electricity from sunlight from both sides of the module. Such a device is not the same as two monofacial modules adjacent to each other from the backside. An important characteristic of a bifacial module is that it is fabricated with transparent or semi-transparent back contacts with the purpose of letting sunlight pass through. Thin wafers are used and in doing so material- and manufacturing cost are reduced. A critical point is the testing under standard test conditions STC (ambient temperature: 25 °C; solar irradiation 1000 W/m²; air mass 1.5) for the front side.

To date no novel standard exists for systematic testing of bifacial modules. It is still common to flash each side of the bifacial module separately.

As it is known that the radiation absorbed by the back side is based on the diffuse radiation reflection from the ground. This Albedo effect plays a vital role in the backside contribution.

Table 1 Albedo for selected environments [6]

[2] Underground surface	[3] Albedo
[4] Green grass	[8] 0.25
[5] Desert sand	[9] 0.40
[6] Fresh snow	[10] 0.80 – 0.9
[7] New concrete	[11] 0.3 – 0.55

An example is the use of bifacial modules in the winter with plenty of snow. After a period of snow fall the front of the module is covered – however, if sunshine returns it takes some time to clear the front as snow slides down due to the inclination. During that time sunlight is reflected from the ground onto the backside and electricity is generated as indicated with **Fig. 5**.

Fig. 5 Bifacial modules in Japan during winter season (Source: 13)

Bifacial cells are also an interesting option in window shades for office buildings and apartment houses [7].

A promising application is the installation of bifacial modules in vertical arrangement along highway or railway tracks. **Figure 6** shows an example from a Swiss highway.

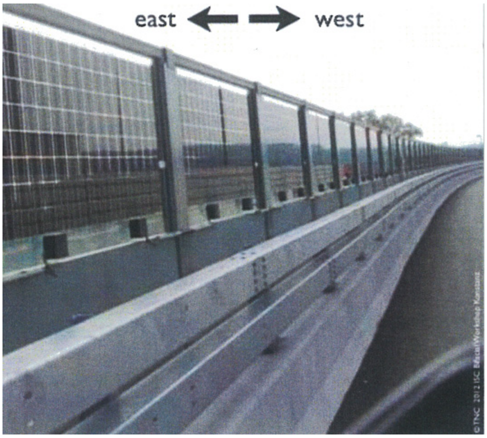

Fig. 6 Swiss highway with vertically installed bifacial modules (Source: 8; TNC)

3.3 Combined systems

Local authorities also focus on sustainable energy supply – but are concerned to find that more and more areas of arable land are used to set up pv plants. Farming and pv plants can be combined. This has been demonstrated by the citizen-solar-park in the town of Sprendlingen/Germany. The company “Gedea”-Ingelheim implemented this novel pv plant, which is depicted in **Fig. 7**.

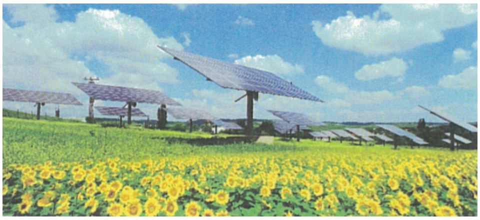

Fig. 7 Citizen-solar-park Sprendlingen
(Source: Gedea-Ingelheim)

The economy has grown increasingly dependent on electricity to deliver many vital services. This trend is expected to continue especially with electromobility. A special example is the charging station for electric motorcycles in Berlin-Adlershof as shown in **Fig. 8**.

Fig. 8 Charging station for electric motorcycle
(Source: R. Hanitsch)

The container below the tracking pv system is housing a storage unit of the redox-flow type.

Due to the fact that the owner has changed, the charging station is not in operation. A more standard charging arrangement with fixed modules is depicted in **Fig. 9**.

Fig. 9 Charging station for electric cars situated at EUREF Campus/Berlin-Schöneberg (Source: R. Hanitsch)

All these examples are a clear indicator that the multifunctionality of photovoltaic systems is providing contributions to the energy sector, transportation sector, the built environment and industry [11, 12].

In the words of Albert Einstein:

"Without changing our patterns of thought, we will not be able to solve the problems we created with our current patterns of thoughts."

4 Summary

The wide use of solar energy will be a vital part of the future power system architecture. However, as electrical engineers we must develop links with civil engineers, and social scientists to exploit the consumer-centric world. There is certainly a trend towards active consumers. The electric car and the solar charging stations are certainly useful modules in order to achieve decarbonisation of the transportation sector.

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