Building integrated PV-modules

Even today there are PV-modules many places as so-called “stand alone systems”, where alternative electricity supply will be expensive (calculating machines, monitoring, sailing boats, lighthouses, traffic lights and mountain cottages). But during recent years the interest in demonstrating use of PV-modules on buildings for local electricity production has been increasing and with connection to the electricity supply system, as a basis for sale of excess electricity in the same way as it is in general for windmills.

It is, however; still expensive to make network-connected PV-systems. But due to the quick rise of the production and the falling prices of PV-modules, where the price has been reduced with 50% each five to seven years since 1978, anyway many countries trust that this technology will play an important role in our future solar energy society.

To obtain the best possible integration and economy of the network-connected PV-modules it is necessary to focus on the possibilities of integrating these in south, south-east and southwest facing facades and roofs on buildings and other constructions. The possibilities are many; a German research has documented that building integrated PV-systems can cover up to 40% of the existing electricity consumption in households.

On a long view e.g. the World Watch Institute thinks that PV-modules can become part of a hydrogen based energy system that also includes fuel cells and a possibility of storing the energy. The systems will be decentralised, which e.g. can be used in the transport sector too.

In a number of countries around us the development of PV-modules, which are building integrated and directly connected to the electricity supply network, has been quick during recent year, e.g. supported by great national plans for implementation of PV-modules in buildings.

However, the level of activity within PV-modules architecture has also increased considerably in Denmark during the last couple of years, both as to initiation of large projects, the common interest of the possibilities with respect to technology/environment and architecture, and participation of the funding authorities.

The purchase price of PV-modules has until now been high and has thus hindered the dissemination. But increased efficiency, increasing environmental interest, improved agreements about network-connected PV-systems and an improved funding policy are, however, expected to turn stagnation efficiently and create a basis for an intensive development and use of PV-modules that during a few years can be very important for the price formation.

Integration of PV-modules in buildings has in addition to the effect as regards energy a considerable impact on the architecture. During recent year a number of good examples of PV-integrated building parts have been made, several manufacturers of building components, e.g. window manufacturers, have developed systems for integration of PV-modules.

Figure 2.6.1.4. Examples of window integrated PV-modules. (a) shows an example from the utility company’s headquarters in Aachen in Germany, both from inside and outside. (b) shows PV-modules integrated in a roof light in the “energy balance house” in Amersfoort in Holland. (c) shows window integrated PV-modules in the

Matero library near Barcelona. (d) shows window integrated PV-modules in the Skibsted Fjord Centre at Nordvestjysk Center for Vedvarende Energy (the northwestern Jutland centre for renewable energy).

Types of PV-modules

In most cases the PV-modules consist of silicon. In principle there are to types of silicon-based PV-modules: crystalline and amorphous, of which the last mentioned type is so-called thin-film PV-modules, where a very thin layer of PV-cells is applied to a glass plate.

The crystalline module is to be found in two types: monocrystalline and polycrystalline. The monocrystalline and the most efficient with up to 17% utilisation of the incident solar energy but also the most expensive. Poly crystalline PV-modules are easier to produce and therefore cheaper. The look of the crystalline PV-modules is different, as close by there are many shades in the polycrystalline PV-modules.

The absolutely cheapest solution per m^3 is the amorphous thin-film PV-modules, which on the other hand only has an efficiency of 4-6%. These PV-modules are originally produced with a yield of approx. 10%, but they are not sufficiently stable to preserve this efficiency in practice.

The amorphous PV-module has a number of advantages over the crystalline not taken the yield into account:

- The price is one third of the crystalline;
- their production requires less energy;
- they have a uniform colour and a homogeneous look;
- they are less sensitive to partial shades;
- they are less sensitive to temperature fluctuation;
- there a great possibilities of reduction of the price.

The PV-modules are opaque but the crystalline PV-modules can be placed with space between the cells in a glass surface by means of which the modules get some kind of transparent effect. Modules made with close cells are not transparent.

In addition to the crystalline PV-modules there are a number of other new types of thin-film PV-modules that are interesting, especially as to the price. There are CIS PV-modules and CIGS PV-modules, for which Siemens has made a new factory, and where the efficiency apparently is approx. 10%. There are also CdTe PV-modules (Cadmium Telluride) for which there are now being established a factory in Erfurt in Germany of 10 MW at the present.

The problem of the last mentioned is, however, that there is Cadmium in the product, like there is also inrechargeable Nickel Cadmium batteries. Even though a 100 % reuse is assured this has to be demonstrated convincingly in practice before you with a clear conscience can consider using the PV-modules, which apparently are cheap to produce.

Finally there are the organic PV-modules, which are in principle also cheap to produce, but are still on the fundamental research stage with many problems to solve.

The orientation and energy efficiency of PV-modules

PV-modules are always made of a number of interconnected cells that form a module. A single cell can only produce 0.5 V. In practice a number of interconnected cells are put together in a module to obtain a useable voltage of e.g. 12 V.

The PV-modules can also be put together to large surfaces. As the produced electricity is direct current it is either going to be used locally to run electricity equipment, which can be run by direct current or converted to alternating current.

If a converter is inserted the possibility of connection the system to the ordinary electricity supply network is obtained. This means that in periods where the electricity production is higher than the consumption, the electricity can be supplied to the ordinary electricity supply network.

It will in connection with electricity consumption be possible to settle PV-electricity by means of an electricity meter that can meter both ways (so-called netmetering).

With regard to orientation and slope of PV-surfaces please see section 2.1. about insolation.

The market and the development abroad

In the PV-module industry and in the running development programmes for PV-modules it is the opinion that the price of PV-modules has to be reduced to 1 $ or 1 Euro pr installed Wp PV-module to make the PV-electricity profitable. Here Wp means maximum power, also called Watt peak. Concurrently the other expenses for network connection; current inverter, electricity installation and building integration should be reduced to almost the same price. Metered in 1000 Wp equal to approx. 10 m² PV-modules this means a price of DKK 7,500 for the PV-modules and DKK 7,500 for the other expenses (so-called Balance of System expenses or BOS-expenses).

Until 1999 the price of 1 kWp or 10 m² PV-modules has typically been approx. DKK 50,000. But in connection with the so-called Sol-300 project (see also section 3.4.3), where 750 kWp or 7500 m² PV-modules are going to be installed on 300 houses in Jutland and Funen, a 20% reduction of the price is expected, equal to DKK 40,000 per kWp. Compared to the above-mentioned aim of DKK 15,000 per kWp the price of PV-systems is still 2.5-3 times too high.

For comparison it can be mentioned that the PV-module producer BP-Solarex states a total price of installed PV-systems on roofs with thin film modules of DKK 50 per Wp by installation of at least 5 kWp. The price of PV-modules is 43% of this. On flat roofs the price is approx. 15% lower, while a price of DKK 35-40 per Wp for large facade installation can be obtained.

A study for the European Commission made by the PV-module producer BP-Solar shows that the driving force as to reduce the price of PV-modules is the size of the market, but also to make a factory with 3000 employees and an annual production of 500 MWp (5 million m²) to reach the aim of 1 Euro per kWp. According to BP-Solar a competitive price of DKK 0.75 per kWh can be reached if a similar size of the BOS-expenses is obtained. For comparison I can inform you that in 1998 the world market was of approx. 160 MWp, of which the USA produced 40% and the European countries 23%.

Realising this state many countries have taken ambitious initiatives to increase the market for PV-modules. In Germany it has been decided to make a 100,000 roofs PV-programme, where a total of 300 MWp are going to be installed during a six years period and the Government gives funding of DKK 4 billion in connection with practical projects. In Japan they are making a 70,000 roofs PV-module programme and in Italy a plan of installation of 50 MWp PV-modules before 2003 has been made. In Holland a voluntary agreement between the Ministry of Economic Affairs, the power industry, the PV-module producers and the building industry has been made, where it is the aim to increase the annual installed PV-effect to 7.7 MWp in 2000, to 100 MWp in 2007, 250 MWp in 2010 and 1400 MWp in 2020. If this programme is realised an annual sale of 100 MWp at a price of DKK 1.5 billion has been created in Holland alone, i.e. a volume of almost the same size as the Danish wind mill industry and at an almost competitive electricity price, provided that similar initiatives will be made in the other European countries.

In the autumn of 1999 an interesting project was initiated in Holland, where 4 utility companies cooperate about getting package solutions with 4 AC-modules with usual alternating current and approx. 0.4 kWp effect installed by 10,000 electricity customers before the end 2001. These systems are designed so the users themselves can install them, directly to the electricity supply network without special authorisation. A package solution of this type consists of an AC module, a modular system for flat or sloping roofs, an energy meter, an installation instruction and the AC module is guaranteed for 10 years. The price per AC module is approx. DKK 3,000.

At present they have in Switzerland the largest installed capacity of PV-modules in the world per inhabitant. In 1998 a total of 1.4 MWp was installed so the total capacity is of 11.5 MWp equal to 115,000 m² PV-modules.

The reason of the successful development in Switzerland is a combination of a strong effort from the Government and the many local utility companies in Switzerland. There are e.g. governmental funds of approx. DKK 15,000 per installed kWp. This is going to be compared to a typical installed price of network connected PV-systems in Switzerland of DKK 60,000 per kWp.

At the same time the utility companies intensify the interest in PV-modules by finding customers who would like to pay an excess price for green electricity and then via some kind of “solar market” allow that solar electricity can be sold directly to them. 38 utility companies are part of this system and more are on the way. Out of 1 million users 2 % have chosen to buy green electricity at a price of DKK 5-6 per kWh. E.g. in Zurich 1 MWp has been installed according to this concept (10,000 m² PV-modules). 4,350 electricity customers do here pay for green electricity from 25 PV-systems that produce 530,000 kWh per year.

There are off course heavy expenses by a large scale extension plan for PV-modules, but if you look at the situation in Denmark it is in this connection inspiring that a research made by DEFU shows that 85% of the Danes go in for more wind and PV electricity and that 73% are willing to pay an extra 10% electricity duty to secure this.

For comparison we have in Denmark today approx. 16 large network connected PV-systems of a total of 242 kWp. Of these are Solgården in Kolding of 106 kWp and Solbyen in Brædstrup of 60 kWp, see also section 3.1.2 and 3.4.2 about these. If you compare the level as to PV-modules in Denmark with the above mentioned countries you will find that we are behind these.

In 1987 the production capacity on world level was on 27 kWp and is from 1991 to 1998 increased from 54 MWp to 160 MWp and the typical production is now of 10-20 MWp per year. The production capacity has thus been increased with 20-30% per year. Figure 2.6.2.2 shows how a continuous development with this growth rate will be on world level. The present electricity production capacity from nuclear power stations will with this expansion be overtaken already in 2023 if there is a 30% growth and in 2033 if there is a 20% growth.

At the PV-meeting at Danish Standard in November 1999 Jan Willem Hendricks from Shell Solar stated that at the moment Shell make preparations for PV-module production facilities with a capacity of 55 MWp in Holland, Germany and Japan and that they expected a continuous development of the market of 22% per year.

The PV-module specialist Peter Ahm from the company PA-Energy has made a suggestion to a Danish PV action plan that matches what is taking place abroad. The idea is here until 2008 to establish 10,000 PV-systems on one-family houses (25 MWp), 100,000 m^2 PV-modules on blocks of flats (10 MWp), 100,000 m^2 PV-modules on industrial building (10 MWp) and 50,000 m^2 on public buildings (5 MWp). This means a total target of 50 MWp in 2008, equal to 0.1 m^2 PV-modules per capita. A plan like this could e.g. be introduced corresponding to the ideas in the Dutch PV-implementation plans.

Figure 2.6.2. Examples of PV-integration in buildings. (a) shows a roof integration in Amersfoort in Holland, where the entire roof surface is PV-modules. (b) shows PV-modules on the facade on the cleaning service R98's head office. (c) shows PV-module/slate roof design from Atlantis Solar, here on a sports centre in Smørum. (d) shows PV-modules integrated in the facade on the Brundtland Centre in Toftlund. (e) shows amorphous PV-modules and a facade system for these from Fortum in Finland. (f) shows PV-modules on a gable in Viktoriagade 10B at Vesterbro in Copenhagen. (g) shows a module design to be placed on flat roofs, which has been developed by the Dutch company Ecofys.

As mentioned above it is the generally accepted view that the development with PV-electricity is going to take place by integration of PV-modules on building surfaces. At the same time there is a good relation between the electricity demand and the possible contribution from PV-electricity from a vertical south-facing building surface.

Studies in Holland and Germany show that suitable building surfaces for integration of PV-modules are equal to 1 and 0.6% respectively of the total area in the countries. In a report from DEFU it is estimated that one third of the Danish electricity consumption can be covered by electricity from PV-modules. This will be equal to a 75 % coverage of the Danish area by PV-modules. According to the above mentioned amounts from Holland and Germany this ought to be done by utilising the suitable building surfaces for this purpose, equal to 324 km^2 or an installed effect of 32,400 MWp. It is therefore clear that even though we start and reach the aim equal to the Dutch with an annual installed effect of 100 MWp in 2020, it will, however, take many years before you can cover up to one third of the electricity consumption with PV-electricity.

The above estimates show that - as the windmill industry has shown – we have to consider large-scale operations, to secure that PV-electricity is giving a important contribution to the Danish energy supply. And if we see to that we start now we might still play an important role in the development in Denmark. E.g. there ought to be good possibilities of specialisation in Denmark within the so-called district heating PV-installations, where the PV-modules produce both electricity and heating. PV-modules can in this connection e.g. be used to preheat ventilation air. Niche application of electricity produced by PV-modules to cover considerable parts of the energy consumption for e.g. ventilation is also an interesting area, where we in Denmark can take the lead.

At the moment there are no real producers of PV-modules in Denmark, but many expert companies, which can deliver special modules and other equipment for building integration of PV-modules at a competitive price. If a basis for implementation of building integrated PV-modules is created on a large scale, e.g. by a small excess price of the sale of electricity, it will result in a number of consequences. E.g. one or a number of necessary European PV-module factories can still be placed in Denmark. Finally you have to notice that in addition to the PV-modules there are many other resulting activities that are going to be made.

An advantage of using local building integrated PV-systems is also that it might have a favourable effect of the electricity production and the distribution network, e.g. by reduction of the transmission loss, by “peak shaving”, by network support and by the possibility of deferred initial investments.

During 1998 a favourable progress as regards extension with electricity produced by PV-modules in Denmark. It was here agreed that solar-electricity is going to be exempted from electricity and CO2 charges in a four-year period and that excess production of solar-electricity can be stored in the electricity supply network without charges. And in 1999 a special PV action plan was adopted, where 30 million DKK are going to be allocated during three years for implementation of building integrated PV-modules.

During 1999 important work about BPS-details of integration of PV-modules in roof and facades has also been finished, BPS-publication no. 127.

Advantages of building integration of PV-systems

There are a number of advantages combined with use of a building surface for production of electricity by photovoltaic modules (PV), which can be supplied to the electricity supply network that has already been installed in the building. Then the produced solar electricity is first used directly in the building and a possible excess of electricity can be supplied to the electricity supply system.

In connection with new building and rehabilitation projects considerable savings can be obtained, both as regards materials and installation, by integration of PV-modules in the ordinary façade or roof surfaces on a building. If a standard building integrated PV-system is installed it can in some case be possible to obtain a lower price of PV-modules than the price of only the PV-modules, as the possible savings of façade or roof surfaces can be considerable.

New examinations show e.g. that on office blocks, where the façade surface often is very expensive, electricity from PV-modules will within a few years be a competitor to ordinary electricity from the electricity supply system.

In office buildings does the electricity production from the PV-modules often follow the variations in the electricity demand. By installation of building integrated PV-modules it is also easier to utilise the production of both electricity and heat from the PV-modules. This can increase the total utilisation of the solar energy from the building integrated PV-modules. The electricity production from the PV-modules can in some cases also be increased because these are cooled, e.g. by heating of ventilation air in connection with a solar wall with built-in PV-modules.

PV-modules can on a long view also operate together with natural gas fired local combined heat and power systems on a beneficial way for the society. The heat demand during the summer is not very large and it sets a limit for a combined heat and power production in this period. Electricity production by PV-modules increases the local electricity production, also resulting in a reduced heat loss. Electricity from PV-modules does not compete with utilisation of solar heating for hot water.

Figure 2.6.3. Examples of integration of PV-modules in the Hedebygade block at Vesterbro in Copenhagen (a) is amorphous PV-modules from Fortum in Finland installed on the window parapet, (b) is PV-modules integrated around a window and (c) is PV-modules integrated in connection with a solar wall façade.

Economy for building integrated PV-modules with a combined electricity and heat utilisation

The calculated value of the annual savings by crystalline building integrated PV-modules is shown in figure 2.16 and 2.17. Calculations for both façade and roof integration of PV-modules have been made of the savings just by electricity from the PV-modules and also where the PV-modules at the same time preheat the ventilation air, which can also increase the output from the PV-modules. The calculations are based a price of electricity from PV-module that in principle is the same the usual electricity price.

Figure 2.18 shows the economy of the PV-modules mentioned in figure 2.16 and 2.17 based on the price of installed modules by large orders, both regarding roof integration and in new or renovated facades. The figure shows that for PV-systems with a combined electricity and heat utilisation the simple pay-back time will be 29-37 years at the moment, while it will be 14-16 years with a 40% reduction of the price of the PV-modules, which is expected within the next 5 years. The calculations do also include maintenance costs of 1% of the additional investments. With amorphous PV-modules you can at best get a pay-back time of only 7 years.

	South facing 45° roof with crystalline PV-modules 1)	South facing façade with crystalline PV-modules 2)		South facing façade with amorphous PV-modules 3)
1. Price of installed building integrated PV-modules including converter and electricity installation (DKK/m²)	4000	4000	4000	2400
2. Total price including design and façade insulation (DKK/m²)	4400	5050	5350 4)	3360
3. Price of usual solution with insulation and ordinary covering, including design (DKK/m²)	500	1440	2350	1440
4. Additional expenses for solution with PV-modules (2-3) (DKK/m²)	3900	3610	3000	1920
5. Simple pay-back time (4/(saving – 1% of the additional investments and maintenance)) (years)	29	37	29	24
6. Total price with a 40% price reduction (DKK/m²)	2640	3289	4125	2016
7. Additional expenses for PV-modules with a 40% reduction of the price (6-3) (DKK/m²)	2140	1849	1775	576
8. Simple pay-back time (7(saving – 1% of the additional investments)) (years)	14	16	15	7

Figure 2.18. Economy of building integrated PV-modules with a combined electricity and heat utilisation. All prices are 1999 prices by large orders.
1) Annual saving: 175 DKK/m² from both PV-modules and preheating of ventilation air exclusive maintenance of 1% of the additional investments.
2) Annual saving: 133 DKK/m² from both PV-modules and preheating of ventilation air exclusive maintenance of 1% of the additional investments.
3) Annual saving: 27 DKK/m² from electricity from PV-modules and 54 DKK/m² from heat utilisation from the PV-modules.