TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS • SCIENCE

15

Arctic solar energy solutions

Riku Pasonen | Kari Mäki | Raili Alanen | Kari Sipilä

VTT

VTT TECHNOLOGY 15

Arctic solar energy solutions

Riku Pasonen, Kari Mäkinen, Raili Alanen & Kari Sipilä
VTT

ISBN 978-951-38-7824-5 (soft back ed.)
ISSN 2242-1211 (soft back ed.)

ISBN 978-951-38-7825-2 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 2242-122X (URL: http://www.vtt.fi/publications/index.jsp)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT
PL 1000 (Vuorimiehentie 5, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 4374

VTT
PB 1000 (Bergsmansvägen 5, Esbo)
FI-2044 VTT
Tfn +358 20 722 111, telefax +358 20 722 4374

VTT Technical Research Centre of Finland
P.O. Box 1000 (Vuorimiehentie 5, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax + 358 20 722 4374

Cover photo: http://www.absolicon.com/_solar_installation/3000_Installationer_en.php

Kopijyvä Oy, Kuopio 2012

Arctic solar energy solutions

[Arktiset aurinkoenergiaratkaisut]. **Riku Pasonen, Kari Mäki, Raili Alanen & Kari Sipilä.** Espoo 2012. VTT Technology 15. 79 p. + app. 8 p.

Abstract

Solar energy installations in Northern Europe mostly consist of small independent PV systems and solar heat collectors integrated to hot water supply of a household. Some larger solar heat plants are in use and have been planned in Northern Europe. Combined heat and power (CHP) solar energy systems are very rare because the concept is challenging but very interesting due to heating needs in the Northern countries. More research in this field is needed and especially in high temperature solar cells to increase possibilities for use of CHP in PV solar plants.

Although solar irradiation is lower in Northern Europe, the difference to central Europe is not large as is commonly believed. The real reason for high PV capacity in Germany compared to e.g. Finland is the feed-in tariff system, not the actual difference in irradiation. Solar heat collectors together with regular heating systems can decrease heating costs in some cases. Prices of solar panels have decreased but PV panel prices in Finland do not appear to reflect global market prices.

Photovoltaic solar energy production integration to energy system poses some challenges. One of the challenges is maximum power tracking of PV panels in power conversion devices to be able to operate at maximum available efficiency on different conditions. Grid protection reliability can suffer from distributed generation units and personal safety issues. Due the fact that solar production is concentrated to summer months and that production fluctuates also daily, there is a limit to how much solar production can be connected to the grid. One option could be to use energy storages to balance plant output but batteries are still too expensive for this. Heat storages are cheaper and they can be used in large solar thermal plants which generate electricity from solar heated steam turning turbines.

Keywords Solar cell, photovoltaic, electricity, energy storage, accumulator, solar irradiation, arctic region]

Arktiset aurinkoenergiaratkaisut

[Arctic solar energy solutions]. **Riku Pasonen, Kari Mäki, Raili Alanen & Kari Sipilä.** Espoo 2012. VTT Technology 15. 79 p. + app. 8 p.

Tiivistelmä

Pohjois-Euroopassa aurinkoenergiajärjestelmät ovat pääasiassa pieniä itsenäisiä aurinkosähkö- ja aurinkolämpöjärjestelmiä integroituna kotitalouksien sähkö- ja lämminvesijärjestelmiin. Muutama suurehko aurinkolämpöjärjestelmä on käytössä Pohjois-Euroopassa mm. Tanskassa. Aurinkosähkön ja -lämmön yhteistuotanto (CHP) on hyvin harvinaisia, sillä tekniikka on vielä kehitysvaiheessa, mutta mielenkiintoinen Pohjoismaissa tarvittavan sähkön ja lämmityksen takia. Aurinko energia sopii myös hyvin rakennusten jäähdytyksen tuotantoon. Aurinkoisella säällä juuri jäähdytyksen tuotanto ja kulutus ovat suurimmillaan. Alan tutkimusta tarvitaan lisää erityisesti korkean lämpötilan aurinkokennoissa, jotka mahdollistavat sähkön ja lämmön PV yhteistuotannon.

Vaikka säteilyn määrä on alhaisempi Pohjois-Euroopassa, ero Keski-Eurooppaan ei ole suuri niin kuin yleisesti uskotaan. Meillä säteilymäärä kertyy vain lyhyemmässä ajassa kesällä. Todellinen syy korkeaan PV kapasiteettiin esim. Saksassa verrattuna Suomeen on syöttötariffijärjestelmä. Peruslämmitysjärjestelmään yhdistettynä aurinkoenergialla voidaan vähentää lämmityskustannuksia. Aurinkopaneelien maailmanmarkkinahinnat ovat laskeneet viime vuosina, mutta Suomessa PV paneelien hinnat eivät näytä seuraavan maailmanmarkkinahintakehitystä.

Aurinkosähkötuotannon integrointi sähköenergiajärjestelmään on haasteellista. Eräs haaste on PV paneelien maksimitehon seuranta muunnoslaitteissa siten, että ne pystyvät toimimaan mahdollisimman tehokkaasti vaihtelevissa olosuhteissa. Verkkosuojauksen luotettavuus voi kärsiä hajautetussa tuotannossa ja henkilökohtaiseen turvallisuuteen liittyvissä kysymyksissä. Auringon tuotannon keskittymisestä kesäkuukausiin ja tuotannon päivittäisestä vaihtelusta johtuen on olemassa raja, kuinka paljon aurinkoenergiaan perustuvaa tuotantoa voidaan kytkeä verkkoon. Energian varastointi on yksi vaihtoehto tasapainottaa tuotantoa, mutta akut ovat edelleen liian kalliita tähän tarkoitukseen. Lämpövarastot ovat halvempia ja niitä voidaan käyttää suurissa aurinkolämpövoimalaitoksissa tuottamaan höyryä turpiineihin auringottomana ajankohtana.

Keywords Solar cell, photovoltaic, electricity, energy storage, accumulator, solar irradiation, arctic region]

Preface

Solar energy based on irradiation in Nordic arctic regions is a focus of this project report. The main goal is to look at solar photovoltaic solutions in the arctic region's point of few. The report contains first a solar cell technology state of the art as well as new and coming technologies, considers utilizing possible technologies in the arctic region. Energy storing, especially in seasonal meaning, is important issue because of long period with low solar irradiation. Storages are also required in islanded systems to supply power over daily irradiation fluctuations. Also impacts of photovoltaic power production to electricity network are inspected.

The project was self-funded by VTT. The project group consists of M.Sc. (Tech.) Riku Pasonen, Dr. (Tech.) Kari Mäki, Dr. (Tech.) Raili Alanen led by Team Manager Kari Sipilä.

Contents

Appendices

List of symbols

kWp	Peak output power in kilowatts
kW_{th}, MW_{th}	Thermal output in kilowatts or megawatts
Fill factor	Ratio of power output to multiplication of short circuit current and open circuit voltage
MV	Medium voltage
LV	Low voltage
DC	Direct current
AC	Alternating current
DG	Distributed generation
COP	Coefficient of performance
PV	Photovoltaic
MPPT	Maximum power point tracking
SCo	Solar collector (thermal)
SP	Solar panel (electricity)
SCe	Solar cell (element of solar panel)
CHP	Combined heat and power plant

1. Introduction

Solar is practically limitless source of energy but use of it in northern Europe has been previously considered to be unpractical. As technology has improved in solar heat collectors and price of photovoltaic (PV) panels has been declining, use of solar energy in Northern Europe has increased. Development has been fastest in small independent PV systems and solar heat collectors integrated to hot water systems of households. Of course solar energy cannot ever cover a large part of consumed energy in Northern Europe because production is focused on summer time. This is one problem of PV applications: load profiles are dominated by heating and hence the load peaks are on periods during which PV generation is naturally low – winters. Solar energy could be used for other generation e.g. to produce cooling in summer time. The consumption demand meets then the top production, when the sun is shining. Cooling can be produced by compressor or absorption machines. Compressor machines use electricity and absorption heat for running. Both of them could be driven by solar energy, when sun is shining.

Network operators have recently been facing new challenges with distributed generation (DG) located along distribution networks. These units have so far been located mainly on medium voltage (MV) levels. The concept of DG requires new thinking since the old way of transferring power “top-down” from high voltage levels towards customer is not clearly valid anymore. Now PV generation can be seen to put this development one step forwards; it extends the range of DG applications to low voltage (LV) networks and to end customer interfaces. Since the LV side is far less automated and made with more simple structures, interfacing PV may be challenging in certain areas. LV networks are initially built with less redundancy than MV networks. Thereby the limits may be reached much easier on LV side.

2. Solar energy systems installed in the Nordic region

2.1 Solar heating in Nordic countries

Heating is an obvious application for using solar energy in the Nordic region. Solar heating can be done with multiple solar collector types but in each case the basic idea is the same; absorb solar radiation to fluid and pump heated fluid to heat exchanger which can be inside a heat storage unit. Figure 1 displays principle of this kind of a solar heating system.

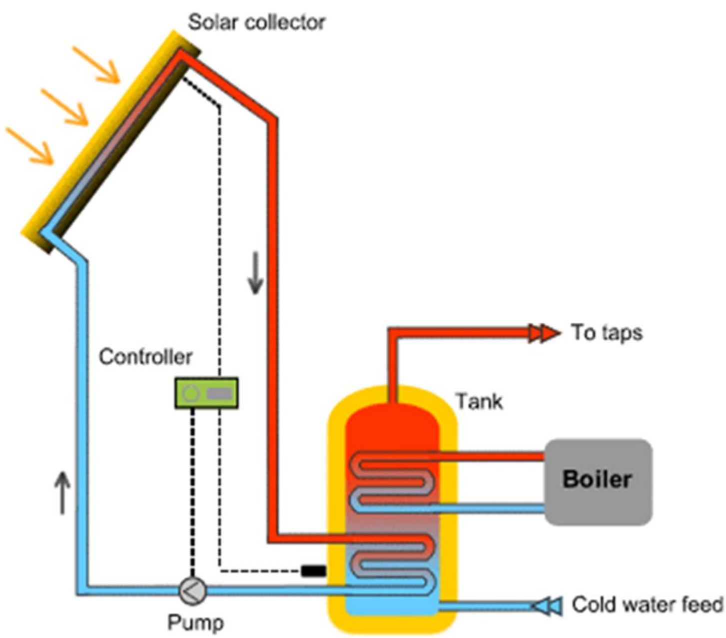

Figure 1. Solar heating principle. (ES renewables 2010)

There is also a boiler drawn in the figure which can be used to supply additional heat.

2.1.1 Large scale systems

Denmark is one of the leaders in large scale solar heating in Nordic countries. Figure 2 displays a large solar collector field which supplies heating to 830 house-holds and covers about 20% of their heating needs.(Strandby 2010)

Figure 2. Solar district heating collector field in Denmark. (Strandby 2010)

Figure 3 displays large scale solar heat production plants in operation up to year 2009.

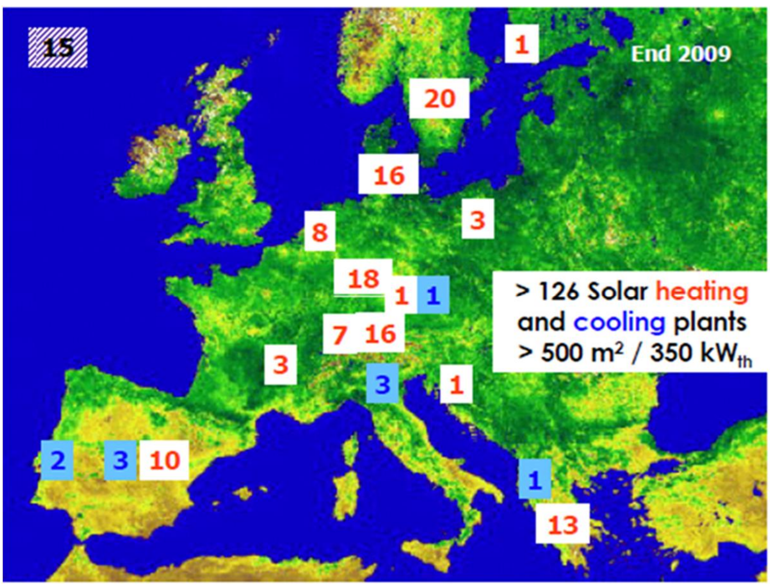

Figure 3. Large scale solar heating plants in northern Europe. (ESTTP 2010)

2.1.2 Small scale systems

Use of solar energy for domestic hot water heating and similar small scale applications is increasing in the Nordic region. Figure 4 displays example of tube collectors installed on a roof of a building in Finland.

Figure 4. Roof installed solar collectors. (SunVoima 2010)

Steep angle of the collector in the previous figure enables better production in the colder time of the year. Tube type collectors usually use vacuum design to reduce convective losses. Figure 5 presents components of a vacuum tube solar collector.

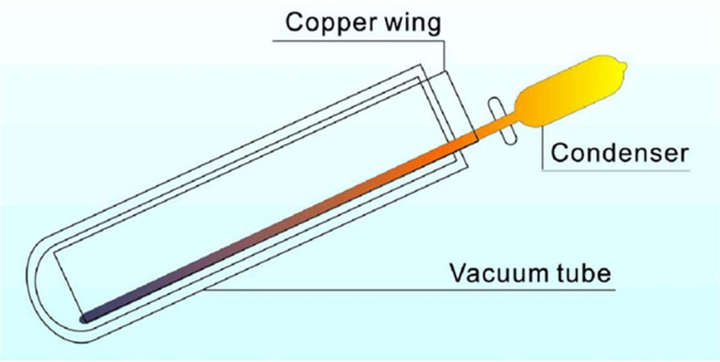

Figure 5.Components of vacuum tube type collector. (Junoka 2010)

Vacuum tube solar collector has a vacuum tube which includes a metal absorber tube which has heat transfer fluid inside. Fluid can be selected so that it gasifies when radiation heats the absorber tube and gas rises up to a condenser. In the condenser heat is transferred typically to a mixture of water and ethanol. When the gas releases the heat, it condenses back to liquid and flows back down to the collector.

2.2 Solar electric power plant types

Power production from sun radiation can be done with photo voltaic (PV) cells or by collecting energy from sun as heat and then producing electricity using steam turbines. PV-panel is the older method out of these two and they are available for all sizes of installations. Photo voltaic phenomenon relates to energy levels in an atom and how photons interact on the surface of the PV-cell. For material to be able to conduct electricity there has to be electrons in conduction band. Electrons of semiconductors need energy to rise to the conduction band from valence band and this energy comes from the sun. Figure 6 has a simplified sketch of the solar cell.

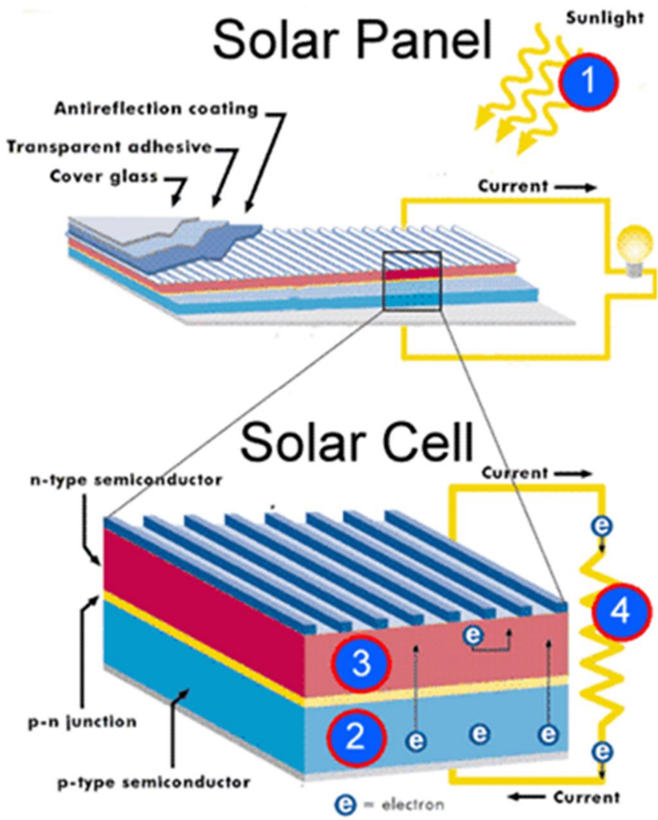

Figure 6. Simplified representation of a single layer solar cell. (Energy masters 2011)

A traditional PV cell consists of negative (n-type) and positive (p-type) semiconductors. Electrons will rise over the PN-junction from the p-type to n-type when radiation gives additional energy to the electron. This generates an imbalance of charge between the conductors. This imbalance can be neutralised with an external conductor between the layers. Current passing through the external conductor can be used to power electrical systems.

Different cell materials can be used to harness energy from solar radiation on different wavelengths. Efficiency of the panel (electric power / irradiation power) can be improved with multiple layers of cells of different materials absorbing wider range of the available irradiation spectrum. Figure 7 represents the best efficiencies of different PV cells with respect to the year of the demonstration. (The figure excludes the new record holder 43.5% efficiency cell in layers of GaInP /GaInAs/Ge).

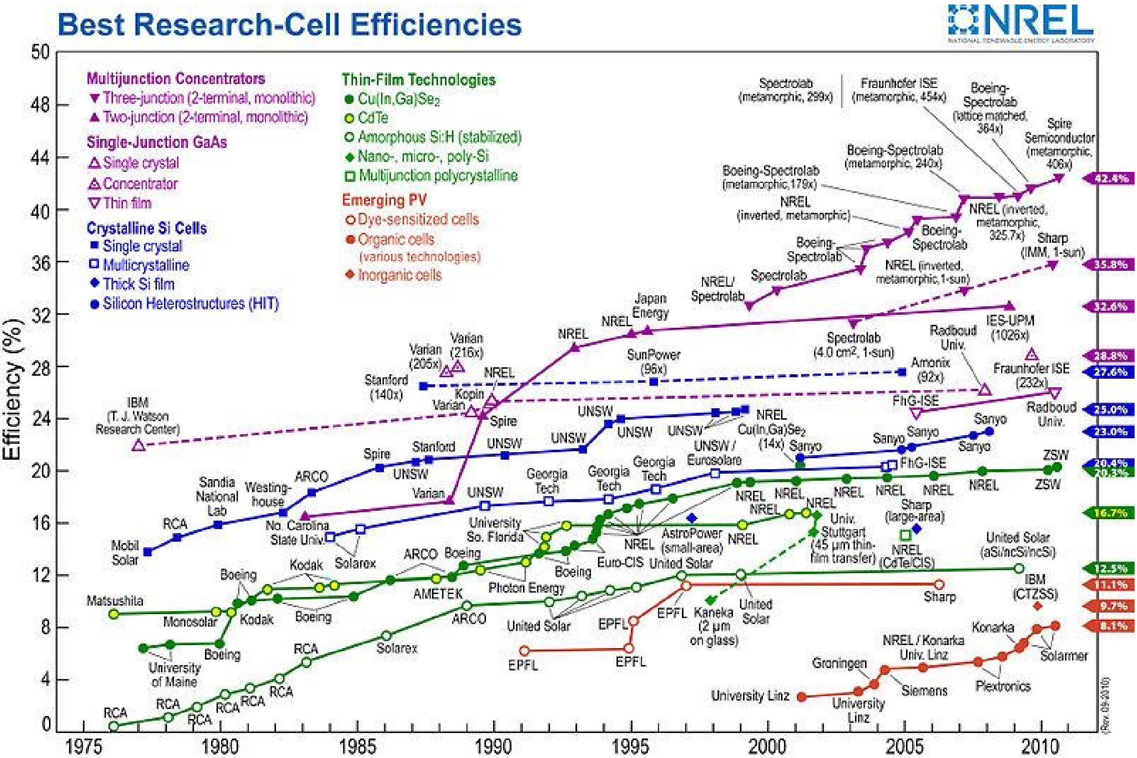

Figure 7. Efficiency landscape of different cells in laboratory conditions. (NREL Wikipedia 2010)

Like mentioned previously, electricity can be produced from solar radiation also with heat collectors connected to a steam turbine and a generator. Figure 8 represents the system process in the Andasol solar power plant in Spain (Andasol 2011).

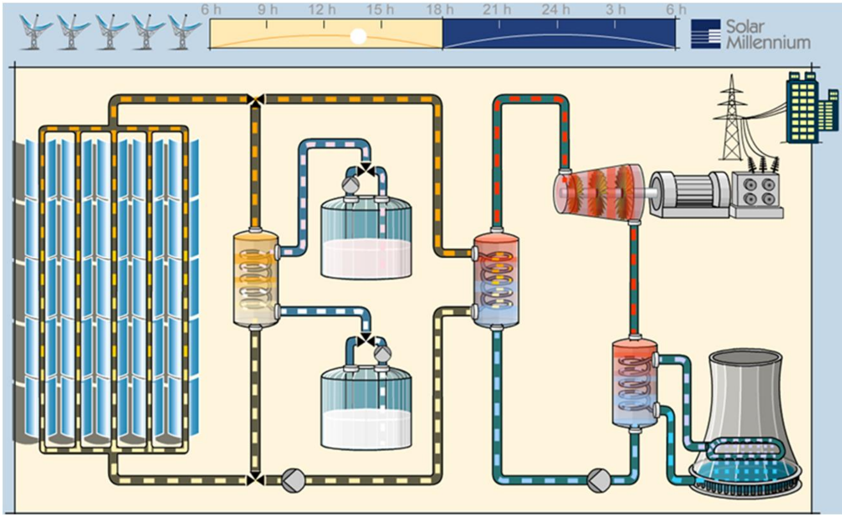

Figure 8. Screen capture from Solar Millenium AG. (Andasol 2011)

System in the figure uses parabolic trough technology which is used to concentrate solar radiation into absorption tube filled with oil. The oil is heated to high temperatures. Energy can be stored into a heat storage (two containers in the middle) or to produce steam. Steam is driven through a turbine which turns a power generator and the generator produces electricity to a power grid. Steam exiting the turbine is cooled down with a cooling tower.

The benefit of a solar thermal system is that power output variation can be minimised because a part of the energy is stored to heat storage and heat storage can be used to output power during night time. Of course energy from PV cells can be stored as well, but currently battery technology is too expensive in most cases. Solar thermal plants with heat storages offer better value in grid control respect because output power can be adjusted without sacrificing efficiency too much. Disadvantage of solar thermal systems is the large size of the systems and PV systems suit therefore to small applications better than thermal systems.

3. Installed solar power plants in Northern Europe

3.1 Large scale solar power plants in the Nordic region

Solar electric power generation plants operating in the Nordic region are relatively small units in terms of power capacity. So term “large scale” can only be used when these systems are compared with other solar power systems in the Nordic region. Currently the largest single plant is installed to ABB factory roof in Pitäjänmäki Helsinki Finland. (Figure 9)

Figure 9. ABB PV-solar plant in Finland. (ABB sol 2011)

The peak power of the ABB plant is 181 kWp and the system is expected to output 108 MWh per year. (ABB sol 2011) Sweden has a 108 kWp capacity plant installed in Glava, which generated 88MWh of electricity in year 2010 (Fortum solar 2011).

3.2 Small scale solar power systems in Nordic countries

Small scale solar power sector in Nordic countries is dominated by installations to locations where electric grid is not available and PV-modules are competitive against the costs of a new grid connection. A typical example of a system is installed to a summer cottage where it supplies lights, TV, and maybe a refrigerator. Usually systems operate at low DC voltage, which means customers can do installation by themselves and save money. Figure 10 displays PV modules installed away from tree line to avoid shading (Solarshop 2011).

Figure 10. Solar panels installed away from treeline to reduce shading. (Solarshop 2011)

3.3 Installed solar CHP in Nordic region

Combined heat and power (CHP); producing simultaneously both electricity and heat from the same power plant is a common way to produce energy in Nordic region using conventional sources like natural gas, wood, coal, and oil. Solar CHP is in fairly uncommon everywhere in the world because there typically is no need for heat in the regions where solar power generation is profitable. Yet are many systems where heat is removed from solar panels to lower operating temperature and improve panel efficiency and heat energy is not used for anything. Figure 11 presents one of the first solar CHP systems installed in Sweden (Absolicon 2011).

Figure 11. Solar CHP system installed in Sweden. (Absolicon 2011)

Absolicon x10 solar CHP technology uses a trough collector and a cooled silicon solar cell. Figure 12 presents cooled PV panel more closely.

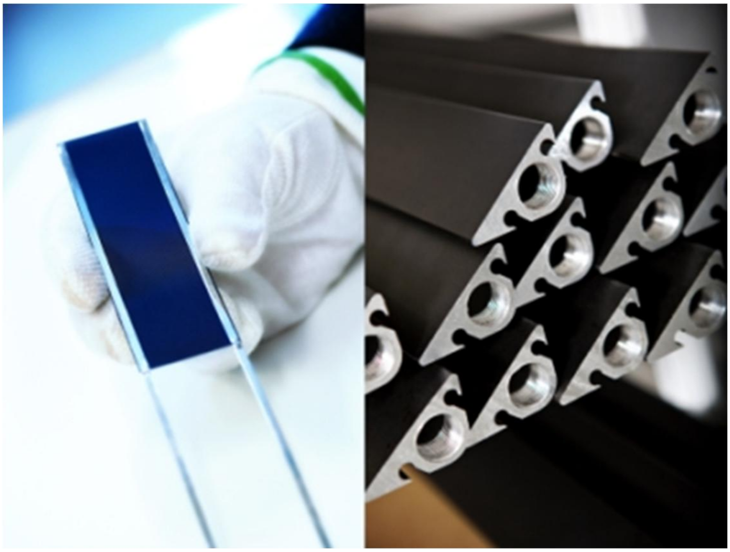

Figure 12. Close picture of a Absolicon X10 PV-panel. (Absolicon 2011)

A larger system using same X10 technology has been installed to Härnösand. The installed system has an area of 200 m² and has a peak capacity of 100 kWp heat and 20kWp electricity. Figure 13 represents one of first solar CHP systems installed in Sweden. (Absolicon 2011)

Figure 13. Solar CHP system with 100kWp heat and 20kWp electricity capacity in Sweden.

The system in the previous figure supplies heat and electricity to a local district heating station. Currently (10.6.2011) there is only a purchase contract for the heat, and electricity is given free to own use of the district heating station.

3.4 Price development of solar energy systems

Price of solar panels has been declining and closing to a point where solar energy does not need vast support in many places around the world. Figure 14 represents global average PV-module prices $ / W (DOE 2010) (panel only).

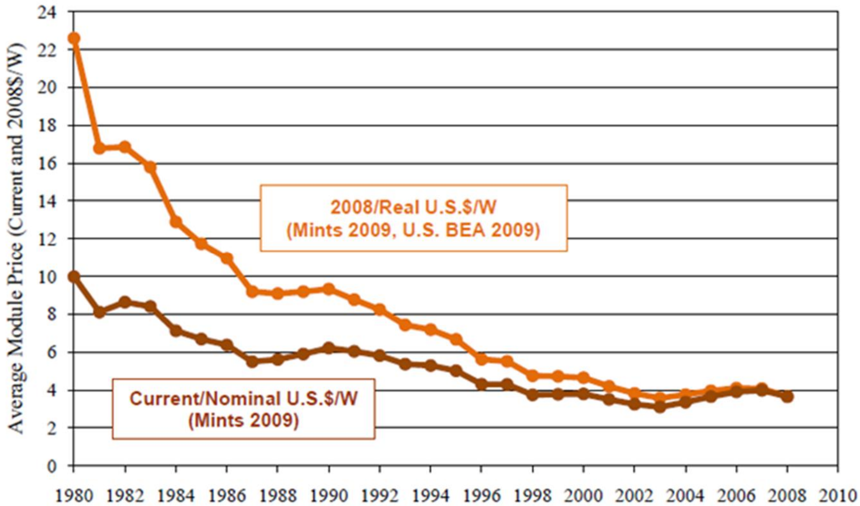

Figure 14. Global average PV-module prices. Darker curve represents nominal prices and lighter curve inflation adjusted prices (DOE 2010).

The data in the previous figure end in the year 2008. Current market prices for the most cost efficient panels are around 1.6 $/W. Price information for 14th of June 2011 is presented in Figure 15. (Ecobusinesslinks 2011) (panel only)

Solar Panel Brand	Peak Power Watts	Minimum Quantity*	US$ per Solar Panel	US$ per Watt
Evergreen Solar	195	2	$310.05	**$1.59**
Evergreen Solar	200	2	$318.00	**$1.59**
Evergreen Solar	205	2	$325.95	**$1.59**
Evergreen Solar	215	2	$341.85	**$1.59**
DuPont	95	2	$160.55	**$1.69**
Canadian Solar	200	20	$340.00	**$1.70**
Canadian Solar	205	20	$348.50	**$1.70**
Canadian Solar	245	1	$428.50	**$1.75**

Figure 15. Price tracking details for solar panels in US for the date 15.6.2011. (Ecobusinesslinks 2011)

PV-panel market prices in Finland do not seem to reflect global market prices. Here are some example prices (panel only):

135W panel, 539€ = 3.99 €/W = 5.74 $ / W (with EUR/USD at 1.44) (Thermosun 2011)
120 W panel, 499€ = 4.15 € /W= 5.976 $ / W (with EUR/USD at 1.44) (Elektroni 2011)
140W panel, 999€ = 7.135 € /W= 10.27 $ /W (with EUR/USD at 1.44) (Marinea 2011).

Because there is no similar price tracking applications available for PV-panel prices in Finland, previous prices do not necessarily represents accurately the whole spectrum of prices in Finland, but give a general idea. The cheapest of the example panels sold in Finland is 261% more expensive compared to the cheapest ones in the US markets in Figure 15 (with EUR/USD at 1.44) Panels are also considerably cheaper in Germany compared to Finland. Figure 16 represents PV-panel €/W prices at one German retailer (PV-shop 2011).

Modul		Typ	Wattpreis
Sulfurcell		SCG 57-HV-L, 57,5 Wp, CIS-Dünnschicht	1,18 €
CETC		ZKX 185D-24 , 190D-24, 195D-24, 185 Wp - 195 Wp, mono	1,48 €
S-Power		PPV-222 M6, 222 Wp, poly Deutscher Hersteller mit Produktion in Taiwan.	1,57 €
CSG		CSGS1 35/36 185 Wp, 185 Wp	1,59 €
Yingli		YL 230P-23b 230 Wp, poly	1,59 €
EP Tech (Eoplly)		EP Tech M125-185, 185 Wp, mono	1,64 €

Figure 16. Example prices of cheapest panels at one retailer in Germany. (PV-shop 2011)

The solution for the price difference would be for customers to import panels from Germany and US to make pressure for domestic prices to come more close to global market. Also contractors and system builders should seek more offers from international markets to improve their competiveness and make larger systems more attractive to their customers.

4. Potential of solar energy in the Nordic region

4.1 Irradiation spectrum and amounts in Finland

Irradiation means the part of solar radiation that arrives to the solar panel surface (or to any surface). Irradiation amounts vary year to year. The most important factor in irradiance is air mass which is used to describe how thick a layer of air solar radiation has to pass to earth surface. If sun shines perfectly from straight up; at zenith, air mass is 1.0. Standard conditions for PV panel performance use a value 1.5 for air mass. Figure 17 displays how the available irradiation is spread to different wave lengths at air mass 1.5. Figure is drawn with data of American Society for Testing and Materials (ASTM) and provided by The National Renewable Energy Laboratory (NREL 2011).

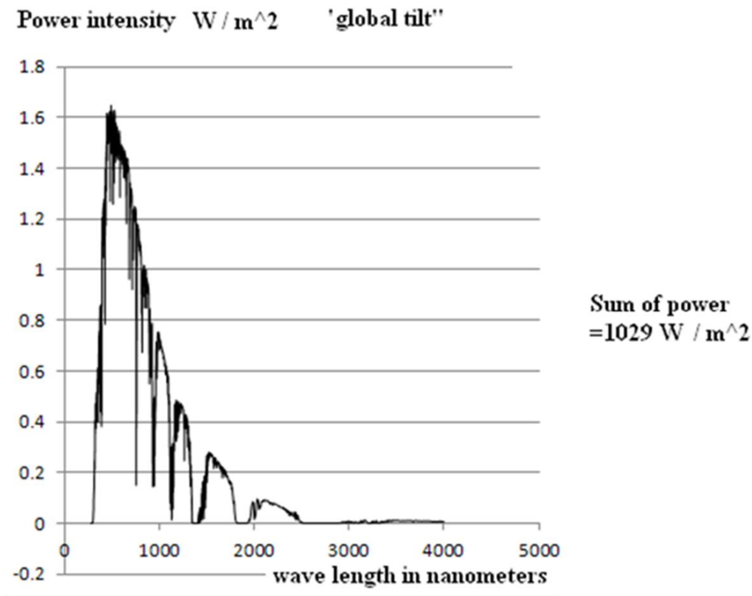

Figure 17. Power intensity spectrum of irradiation at air mass 1.5. (NREL 2011)

Because air mass changes between years and days, available power changes also. However, yearly irradiation energy varies much less. Table 1 represents average daily irradiation energy in different months calculated by the European commission (EC) PV potential estimation utility. PV potential estimation utility is a part of EC's Photovoltaic Geographical Information System (PVGIS) (EC 2008).

Table 1. Daily average irradiation in Wh/m² to Tampere region (inclination 0º). (EC 2008)

Month	**H_h**
January	218
February	867
March	1930
April	3660
May	5120
June	5430
July	5250
August	3660
September	2110
October	899
November	284
December	112
Year	2470

Average daily irradiation of 2.47 kWh equals 901.55 kWh over a year. Irradiation in Tampere has been measured by Tampereen sähkölaitos, a local utility company during years 1985 to 1992. Irradiation in the measurements was between 726.3 and 817 kWh (inclination 0º). Tampere University of Technology has also done their measurements and results were relatively close to measurements done by the utility company. (Kitunen 2007) Thus it seems at least in this case, that the PV potential estimator gives a bit too optimistic values compared to actual measured values.

4.1.1 Comparison of Nordic region to other EU countries

Although the irradiation estimations from EC PVGIS can differ from measurement data, it can be estimated that countries can be compared with satisfying results with each other using data from a single application or measurement method. Table 2 displays yearly irradiation amounts calculated with EC PVGIS for optimum static angles (EC 2008).

Table 2. Global yearly irradiation by PVGIS. (EC 2008)

	Global yearly irradiation (kWh/m2)				
	min	**min_urb5**	**countr_avg**	**max_urb95**	**max**
MT	1976	**2003**	**2004**	**2011**	2019
CY	1847	**1905**	**1941**	**1960**	2012
PT	1642	**1746**	**1873**	**2007**	2053
ES	1179	**1500**	**1819**	**1965**	2094
TR	1172	**1454**	**1724**	**1894**	2051
GR	1349	**1516**	**1671**	**1824**	2009
IT	931	**1408**	**1664**	**1956**	2057
MK	1394	**1402**	**1611**	**1706**	1786
RO	1268	**1423**	**1534**	**1600**	1671
BG	1264	**1387**	**1484**	**1550**	1778
HR	1288	**1332**	**1482**	**1823**	1894
FR	1004	**1146**	**1437**	**1793**	1986
HU	1278	**1337**	**1395**	**1480**	1519
SI	892	**1306**	**1355**	**1420**	1640
AT	957	**1231**	**1377**	**1420**	1978
SK	1069	**1196**	**1280**	**1367**	1421
CZ	1083	**1136**	**1172**	**1231**	1286
LU	1127	**1142**	**1156**	**1177**	1185
DE	984	**1087**	**1157**	**1264**	1795
PL	1100	**1137**	**1162**	**1180**	1398

LT	1130	**1133**	**1167**	**1202**	1216
LV	1143	**1147**	**1180**	**1214**	1223
BE	1076	**1078**	**1111**	**1139**	1179
NL	1080	**1085**	**1115**	**1146**	1183
DK	1078	**1108**	**1129**	**1159**	1183
EE	1132	**1138**	**1152**	**1171**	1196
IE	956	**1050**	**1092**	**1148**	1198
UK	844	**1015**	**1090**	**1202**	1277
SE	645	**1056**	**1079**	**1143**	1171
FI	837	**1044**	**1054**	**1163**	1190

It is no surprise that the Nordic countries are found at the bottom end of the irradiation table. However an interesting fact is that, Nordic countries are close to countries like Germany and Belgium which are commonly seen as much better places for solar power than the actual difference implies. Same conclusion was made in (Kitunen 2007). Real production differences between Nordic and Central European countries can even be lower because efficiency of traditional PV-panels will increase in lower temperatures. The real reason for high PV capacity in Germany compared to e.g. Finland, is the feed-in tariff system, not the actual difference in irradiation. Figure 18 illustrates the differences in certain European cities.

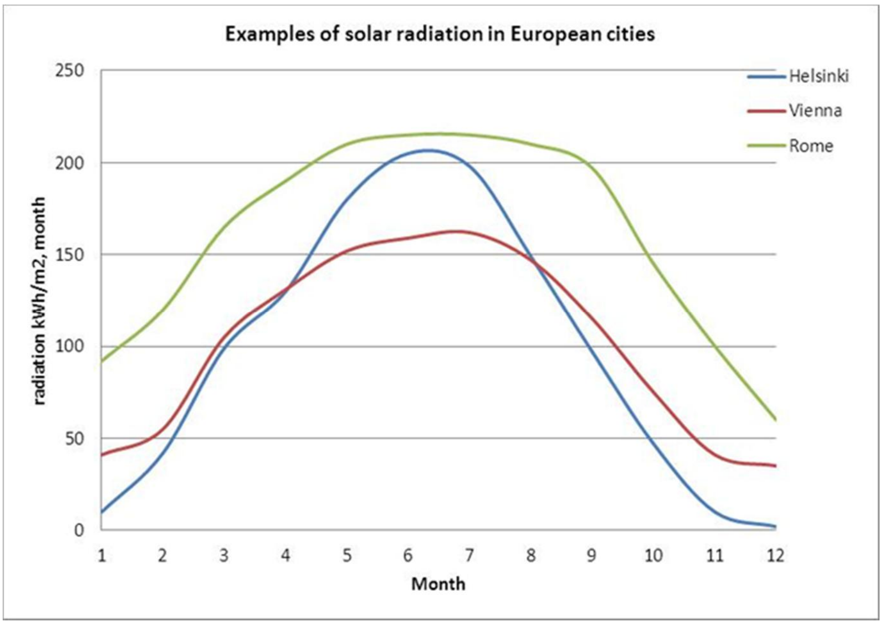

Figure 18. Examples of solar radiation in European cities.

4.2 Snow poses challenges for solar energy in Nordic region

Snowy weather is common in the North and snow can reduce solar panel and collector performance if it is not cleaned during winter time. Of course when it snows, also available irradiation is lower because radiation is partly blocked by the snow flakes and clouds. But after snowfall, panel should be cleaned so that energy harvesting can continue. Figure 19 represents PV-panels cleaned after heavy snowfall (CNET 2009).

Figure 19. PV-panels cleaned from snow. (CNET 2009)

Better option is to try to prevent snow accumulation on panels in the first place. Panels themselves should be equipped with hydrophobic coatings which reduce friction of panel surface to snow and raindrops. Also wind can be used to clean panels from snow as displayed in Figure 20 (Rimstar).

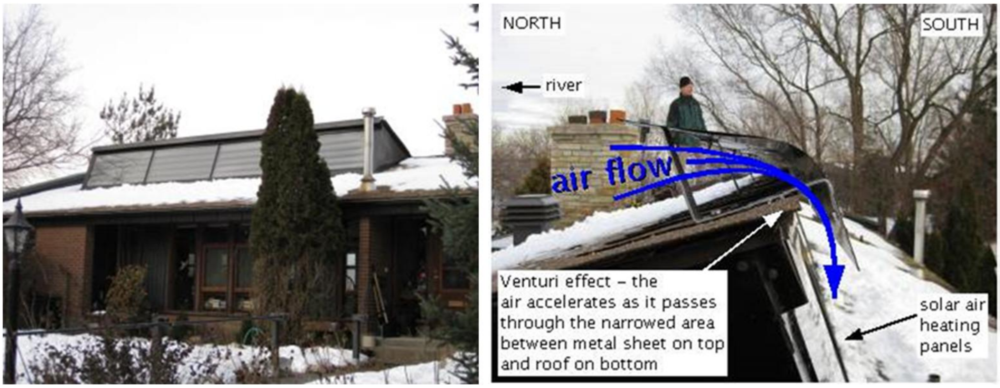

Figure 20. Venturi tunnel used for cleaning snow from panels. (Rimstar)

In the previous figure, wind is forced through a narrowed area to create high speed airflow to panels and snow accumulation can be minimised. Other possibility is to use steep enough angle in panels such that snow will always slide off. In this case there should be enough clearance so that there is no possibility for snow to pile close to the panel. Figure 21 displays instructions on this type of installation and warning about melting snow falling from roof installations.

Figure 21. Instructions to mount PV panel so that snow won't bother the panel and warning about melting snow from the roof. (Rimstar).

4.3 Solar photovoltaic potential integrated to buildings in Finland

Most of the buildings are residential buildings in Finland. The total residential area was about 273 420 000 m^2 in 2010 (Statistics Finland 2010), where 67% was 1-floor residential buildings, 28% 2-floors and the rest 3-floors or more. Very roughly can be evaluated that the roof area of those buildings is about 244 890 000 m^2. One quarter of that roof area could be faced towards the right direction for solar utilisation (to the South or near). If 60% of that roof area could be used for solar photovoltaic, then we could have 33 730 000 m^2 of solar cell area. The average annual solar radiation to the surface is about 900 kWh/m^2,a in Finland. The potential electricity harvest of solar PV cells with 10% efficiency would be about 3 TWh a year on the roof area of the residential buildings. The potential of solar electricity generation could be much more increased, if we use also wall area of those buildings facing South and roof and wall area of other types of buildings: office, commercial, industrial, and public buildings. Also noise barriers on the side of roads and highways, free land and sea surface areas have potential for solar PV generation.

5. New solar energy technologies

5.1 3D-solar cells

A group of researchers in University of California Berkeley have built a prototype of a 3d solar cell. The cell is constructed with nanotubes acting as n-type semi-conductors. Efficiency of the cell was 6% which is higher that of the previous nanostructure cells. Advantage of the structure is that it can perform well under indirect irradiation because “sides” actually produce more electricity that irradiation coming straight. This fact makes the technology promising for Nordic region where there is a lot of indirect irradiation. Figure 22 represents this 3d solar cell.

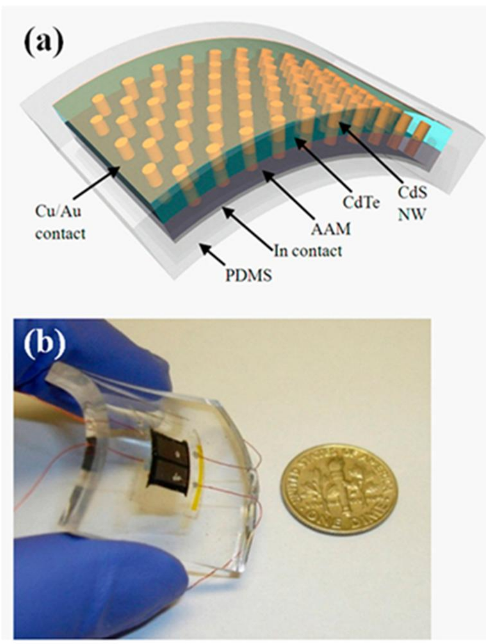

Figure 22. Berkeley prototype 3D solar cell.

5.2 Cells to harness Infra-red band

Typical solar cells cannot harness energy from infrared band; wavelengths above 700 nm. Solar cells operating using infra-red spectrum have been researched by many developers. Rice University in Texas has developed antenna which can generate electrical current from infrared radiation. Antennas were made from 100nm long gold stripes which connected to semiconductor material were able to convert infra-red radiation into electrical current. The research team aimed the invention to enable infrared light detection but they also believe in possibilities for energy production (Knight et al. 2011).

MIT has developed transparent solar cell which can convert infrared radiation into electricity. Efficiency of the prototype panel was said to be 1.7% and 12% was told to be achievable with improvements. Fraunhofer Institute for Mechanics of Materials has developed similar cell in 2009 which requires two coatings on a cell opposed to only one coating with the MIT cell (Ecoseed 2011).

Spectrolab has been able to harness infra-red spectrum with their efficiency world record holding multi-junction solar cell. Multi-junction technology is explained briefly in the next chapter.

5.3 High efficiency multi junction cells

Multi-junction solar cells are made from layers of different cells to absorb broader range of the irradiation spectrum. Solar junction currently holds efficiency world record for photovoltaic cells with efficiency of 43.5% (Solar junction 2011). Figure 23 represents structure of a similar type multi-junction cell as with record cell and U/I curves of the subcells and total curve (Spectrolab 2011).

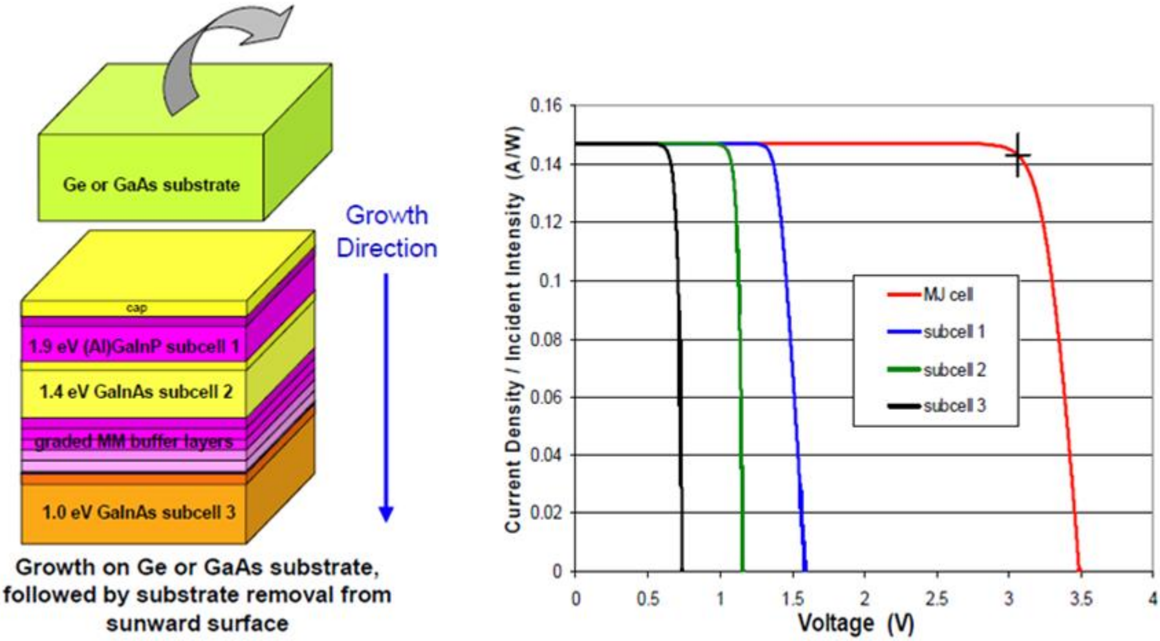

Figure 23. Structure of a multi-junction solar cell and U/I curves of the different subcells. (Spectrolab 2011)

The world record holder cell can harness wide range of irradiation. Effectiveness of the panel to convert photon energy into electrical current can be described with Quantum efficiency. Figure 24 represents quantum efficiency of the cell, which achieved 41.4% efficiency with red curve. (Spectrolab 2011)

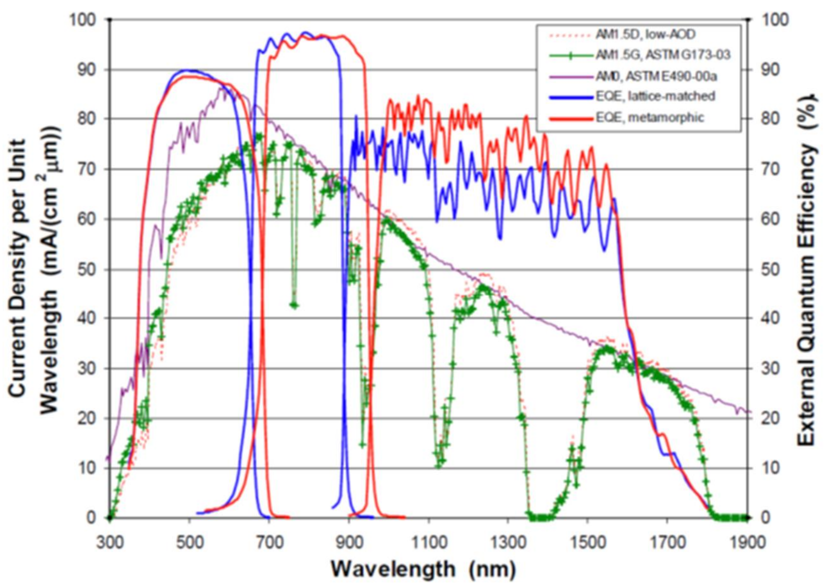

Figure 24. External quantum efficiency of Spectrolab solar cell. (Spectrolab 2011)

High efficiency of the multi-junction cells can be achieved by concentrating irradiation, which accounts for hundreds of times the normal irradiation. At 1.0 times sun irradiation, efficiency of the Spectrolab cell was only 32%. Multi-junction cells are best to be used therefore with concentration systems like in CS500 system by Solar systems displayed in Figure 25. (Spectrolab 2011)

Figure 25. Solar systems CS500 dish field. (Spectrolab 2011, Solar systems)

5.4 Solar CHP with photovoltaic panels

This chapter investigates new possibilities to use photovoltaic panels in a combined heat and power system. Classification is made by dividing system into high temperature and low temperature systems. High temperature systems are focused to produce heat for district heating and low temperature systems are focused on maximising electricity production of the panels. Combining PV with solar collector has an advantage when available space is limited compared to separated systems. Solar CHP can also be cheaper than separated systems.

5.4.1 High temperature CHP with PV

General problem with combined heat and power with photovoltaic panels, is that for the panels to be operated at optimum efficiency, they have to be cooled down from temperatures in which it would make sense to use the heat for district heating. Solution to this problem might be to use solar panels efficiency of which would increase when temperature increases or efficiency would decrease less than with conventional cells. Thin films cells like Dye-desensitized solar cells can have this kind of an effect like reported in (Berginc et al. 2007). Amorphous silicon cells have also shown same effect as documented in (Taguchi 2007).

National Aeronautics and Space Administration has also been developing high temperature solar cells for space programs. GaInP solar cell developed for high temperatures, was documented in (NASA 2005) to lose power only 0.177% / ºC. The maximum fill factor for the GaInP cell was achieved at 120 ºC, which would be high enough for district heating purposes. The same article sees GaInP, GaN, SiC and GaP type cells to be promising for high temperature operation. Basic idea for these cells is to have wider band cap to achieve better efficiency at higher temperatures. Figure 26 presents efficiency of different PV-panels as a function of temperature. (EFP 2003).

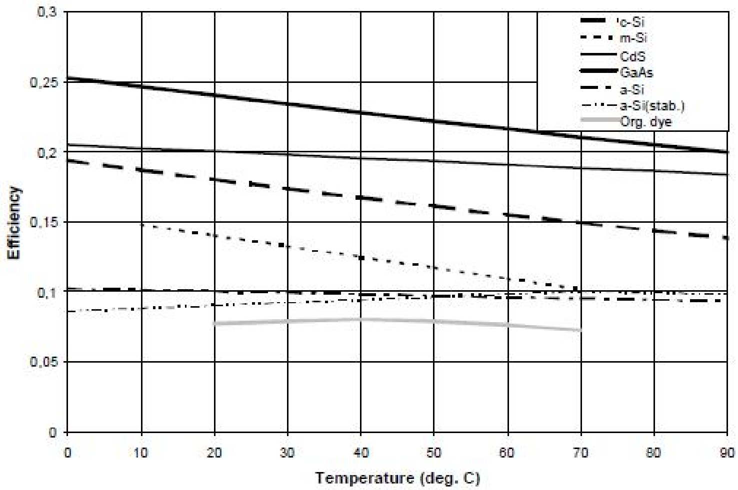

Figure 26. Temperature dependence of efficiency of different PV panels. (EFP 2003).

5.4.2 Low temperature CHP with PV

Low temperature solar CHP means that a goal is to cool photovoltaic cell as much as is sensible for the best efficiency (taking into account the power usage of cooling). Basically the system displayed in Figure 25 is this kind of system but the heat from the panels is dumped and not used for anything meaningful in most cases. Low output temperature (typ. 20–30 ºC) of these types of systems makes it impossible to use the heat directly for district heating. Heat pumps can be used to transfer energy from low temperature heat to heating or low temperature heat can be used to preheat warm water. Principle of this is presented in Figure 27 (Solartubs 2011).

The cooled panel is on the left in the figure. Heat from solar panel is stored to own tank with heat exchanger. Cold water is pumped through the solar heat tank to preheat it before it comes to the main hot water tank. This way electricity can be saved because energy harvested from the sun directly is saved in electricity consumption of the water heater.

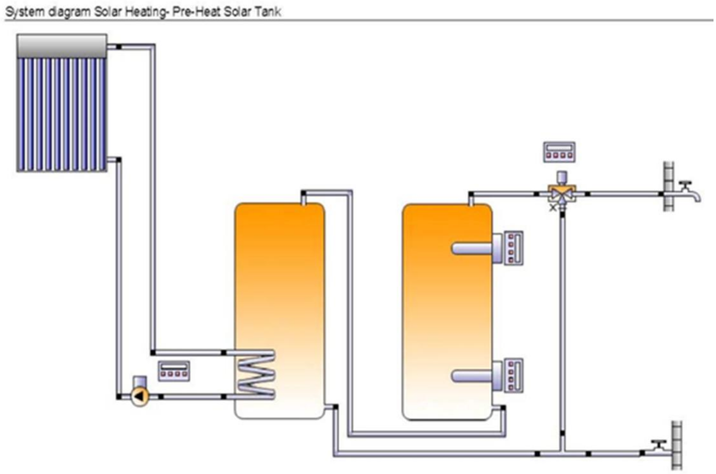

Figure 27. Solar energy used to preheat cold water coming to water heater. (Solartubs 2011)

5.4.3 Optimisation considerations on solar CHP

Many directions can be chosen when optimising solar CHP system operation and design. Optimisation goal can be e.g. total yearly energy production, electric efficiency,exergy efficiency, minimum costs of heating and electricity, or best financial result for plant owner. For single house applications, suitable optimisation goals are maximum exergy efficiency and minimum energy purchase costs.

Exergy is a part of energy which can be theoretically converted to work in Carnot cycle (ideal thermal machine). An example of high exergy is system that produces heat in cold environment or cooling in hot environment. Exergy therefore also describes how usable produced heat or cooling power is in different conditions.

Minimum energy purchase costs take into account produced heat and electricity in their monetary values instead of energy or exergy values. All financial calculations should be made using net present cost or similar method, which takes into account effect of interest rates and time in years, but of course also all related costs and savings. Although solar CHP system might not produce more energy than separate PV and collector, but total cost might be cheaper.

Optimisation calculations for solar collector design have been made in (EFP 2003). When using PV panel which is cooled from back side, adding an acrylic cover plate increases exergy efficiency of the system. Also with cover plate, the best exergy efficiency was achieved with higher operating temperature. Absorption and emission coefficients of PV panels have large effects on the performance of a CHP system. According to (EFP 2003) “ratio absorptance/emittance of 0.95/0.1 gives app. 18% more energy than the ratio 0.90/0.95”. Absorption coefficient of PV panels is usually 0.9 and emitting coefficient can also be of similar magnitude.

Emission can be lowered by different coatings applied to panel surface. (EFP 2003).

5.5 Solar heating and heat pumps

Heat pumps are a common heating solution in buildings of the Nordic region. Use of solar heating in combination of ground source heat pumps has been investigated in (Kjellsson 2010). The conclusion of the study was that solar heating can be used to reduce electricity consumption by heating with a ground pump connected to bore hole(s) during winter and using solar heating in summer time directly for domestic hot water. However if bore hole(s) is deep enough, there is no advantage in heating bore whole(s) with solar heat. But if bore holes are short, solar heating can give significant electricity savings.

Use of solar energy together with air heat pumps has been investigated in (Kaygusuz & Ayhan 1998). The results show that both systems benefit from each other and this co-operation can lead to significant savings. The best option for connecting solar collectors is to use system that can switch from series operation to parallel and vice versa. Series operation is profitable during colder time of the year when heat from solar collector is used to rise heat pump operating temperature and increase COP. In time when solar collector (or cooled solar cell) temperature is higher, the heat is used directly for heating purposes and not lead through the pump. Figure 28 displays the results for the different ways to use solar energy together with a heat pump and a comparison to stand-alone solar heating (Kaygusuz & Ayhan 1998).

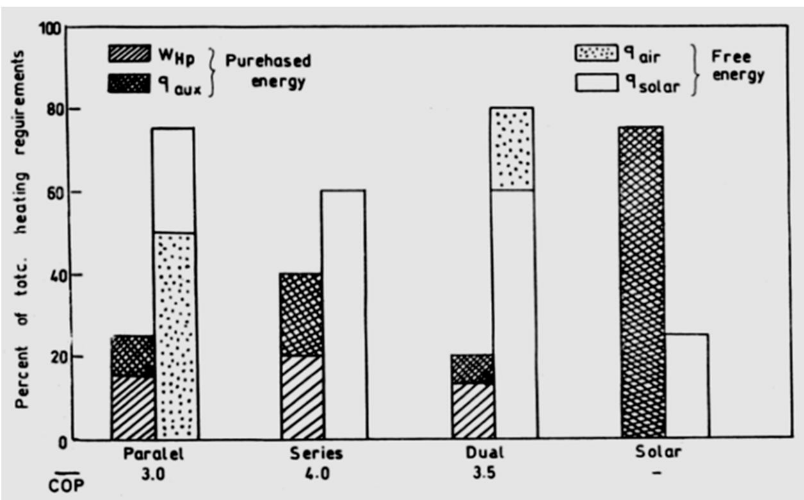

Figure 28. Comparison of different ways to use solar heating together with heat pump (Kaygusuz & Ayhan 1998).

The system with an ability to operate in series and parallel is named as “Dual” in the figure. Coefficient of performance (heat output of pump / electricity used= COP) is marked to the horizontal axis. Best COP is achieved with series connection but a dual system manages to supply more energy over the year as it is basically “best of both worlds”. On the right there is stand-alone solar heating system, which shows clearly the worst performance. (Kaygusuz & Ayhan 1998).

5.5.1 Cooling of solar energy systems

A solar energy system can be cooled with many methods from simple passive convective solutions to advanced water jet injection. Usually highly technical solutions are used with concentrated photovoltaic plants, where cell operating temperature is critical to conversion efficiency and to life-time of the cell. A typical cooling system has circulating closed loop liquid cooling and a pump for circulating fluid between cell (or collector) and heat exchanger. Cooling methods for maybe the most demanding application, concentrated illumination solar cells have been given a review in (Royne et al. 2004). Figure 29 displays thermal resistances of different cooling methods collected in the study.

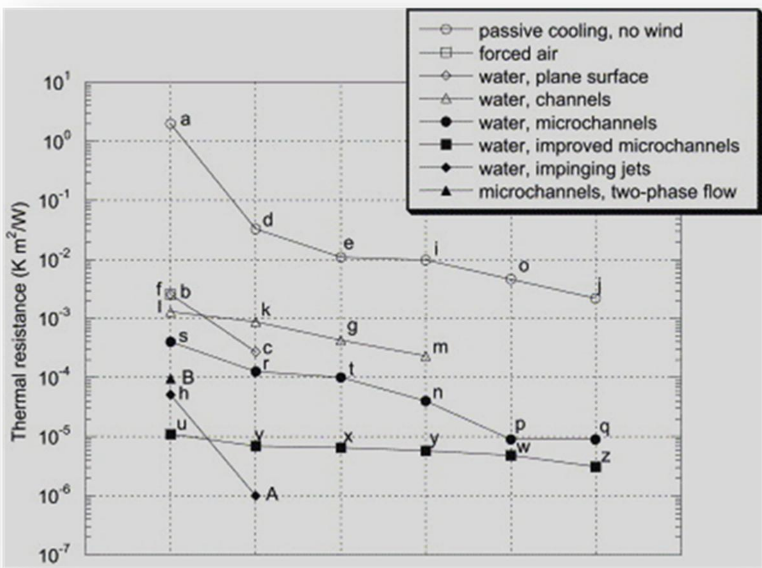

Figure 29. Thermal resistances of different cooling methods for concentrated PV (Royne et al. 2004).

The best cooling performance according to the figure can be achieved with water cooling either by improved micro channels or by impinging jets. Micro channels mean manufacturing heat sink with micro meter scale shapes so that cooling area increases. Jets mean use of high flow rate fluid to small area to extract more heat.

6. Interconnection challenges of PV panes

Direct current PV panels alone cannot be used to produce energy directly to electricity grid. Some devices are needed for connecting system to grid, converting electric power properties, protecting the system and persons from faults and storing produced energy for later use.

6.1 Balancing power still the bottleneck for massive PV installation

Nameplate capacity of grid connected PV-cells in Germany reached 17 GW in 2010. Currently the growth rate of the capacity has decreased a bit and cumulative amount is about 18 GW. PV-systems have generated challenges for grid stability and even some previously base load generation units have to be switched off, when sun shines the brightest during daytime. Problem could be solved by storing excess energy to energy storages and this way balancing the power output of the solar array. However, batteries are still too expensive to be used in balancing. It is clear that this current growth rate of grid connected PV systems cannot continue like this for long time. One option would be to use a thermal solar power system describes in a chapter 2.2 which use thermal energy storages to balance the power output. Another way is to have a regulation to limit the PV system capacity or to give support only to systems which can keep power output variation within reasonable limits.

6.2 Challenges with power conversion

Power conversion devices related to PV systems include charge controllers which control charging of a battery system, DC/DC converters which are used to adjust voltage level, and inverters which are used to convert produced DC voltage to AC voltage. One of the most difficult challenges of power conversion related to PV system is a requirement to harness maximum available power from the system at fluctuating environmental conditions. This ability is also called maximum power point tracking (MPPT). Figure 30 displays the current – voltage characteristics of an example solar panel (Wikipedia 2011)

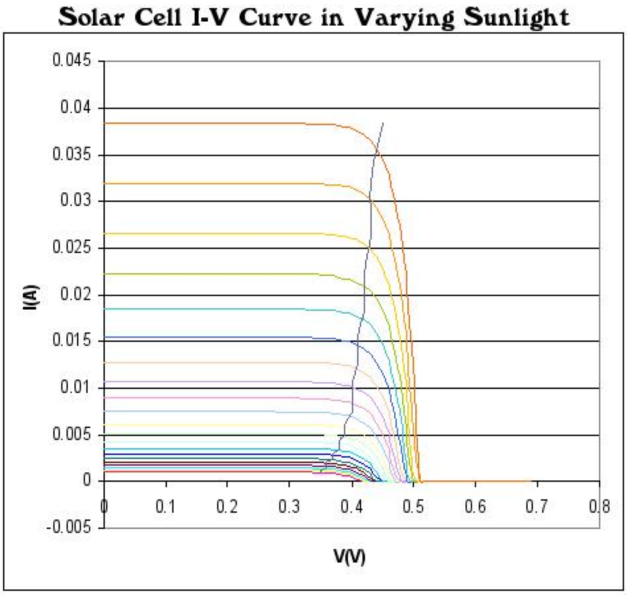

Figure 30. Example PV panel U-I characteristics. (Wikipedia 2011)

The figure illustrates that maximum power point is found around the bend of the U/I curve but actual values of voltage and current differ respect to irradiation, which is of course understandable as available power changes. The challenge for the device is to know whether it is drawing a right amount of current from the PV system. So ideally power conversion device has to adjust operating parameters according to conditions. Most demanding conditions are when panels are partly shaded by moving shadows from trees Clouds also shade panels but this is easier to handle for maximum power tracking device. Ideally of course, panels are installed to location with no possibility for shading but in practice this is rarely possible with small scale installations. The problem becomes even more demanding, if panels are installed in series (opposed to parallel), because then the U/I-curves are not easily predictable in different environmental conditions.

6.3 Protection problems associated with grid-connected PV systems

The majority of PV units are installed as distributed generation (DG) units, which means that they are located along distribution networks as small units. Generally, installation of PV panels is quite straightforward in distribution networks. However, some problems may occur and they may cause safety hazards. That is why they need to be taken seriously. The problems can be divided in three subgroups: disturbance to existing network protection, unnecessary protection operations and local safety problems.

6.3.1 Protection operation disturbances

Following the concept of DG, the PV units are normally installed along feeders on MV and LV networks. Depending on the circumstances, feeders may be protected from the feeding substation or they may also be equipped with additional protection units along feeders. The DG connection point is equipped with a dedicated protection unit.

In the cases in which the DG unit and network are feeding a fault in parallel, the fault current fed by the network is decreased due to current division between the sources. This can become a problem especially in LV networks, where protection is mainly carried out by fuses. Figure 31 shows an example case in which slower fuse operation is possible.

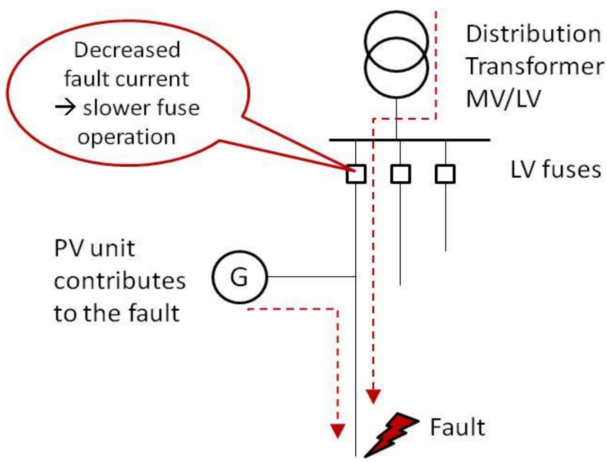

Figure 31. Example case with arrow vectors representing fault currents.

Even a small decrease in feeder fault current will result in slower fuse blowing, which may be a safety problem since the fuses have been dimensioned without DG. A simulated example of slower fuse operation is presented in Figure 32. PV is not the most severe form of DG in this sense due to inverter connection and low powers. It can still be said that each PV unit installed will make the fuse-based feeder protection a bit slower. Especially the aggregate impact of many units can become significant, which is illustrated with a simulation example in Figure 33.

On MV level feeder, protection is mainly based on overcurrent relays which are typically of a definite-time or an inverse-time operation. Definite-time overcurrent relay is unlikely to face disturbance problems with PV installations, whereas inverse-time relay behaves similarly to fuses on LV level. However, more power is needed for any impacts on MV level. PV units located in public LV level can practically not affect the MV level.

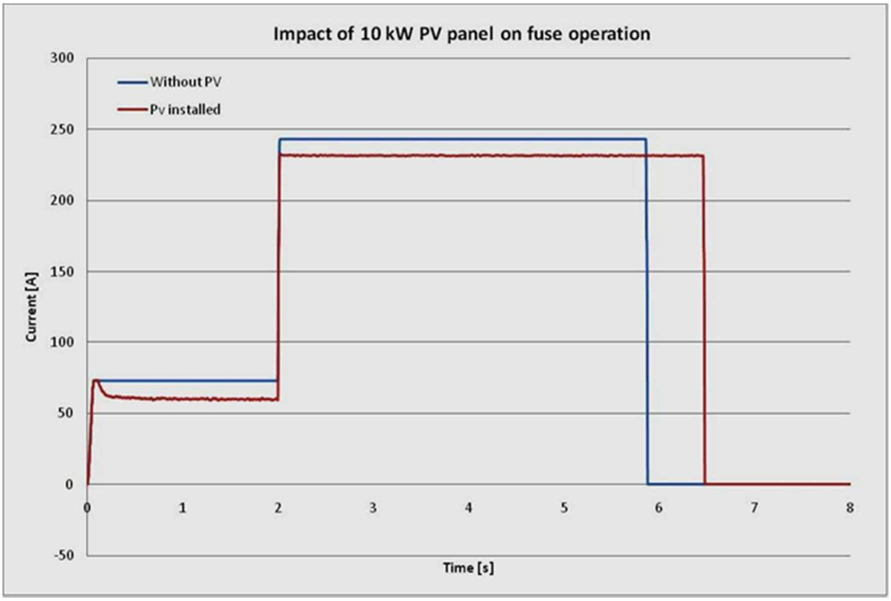

Figure 32. Simulated example of installation of one 10 kW solar panel on a typical rural LV feeder. A one-phase short circuit fault occurs at 2 s. Impact on fault current and especially on fuse operation time can be seen.

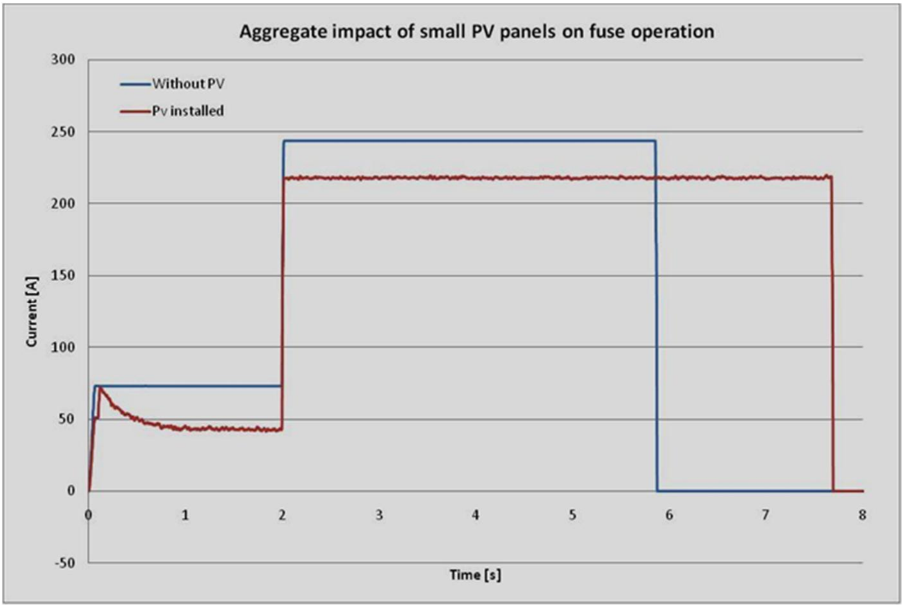

Figure 33. Simulated example of slow fuse operation caused by multiple small PV units distributed along LV feeder. In this case, PV units were six 2 kW units located along feeder. Impact is similar to previous figure.

Another typical protection disturbance cause is failing autoreclosing. If the DG units remain connected to the network during autoreclosing sequence, they may maintain the arc in the voltage point for the reclosing open time. As the reclosing is made, the fault seems permanent and a longer interruption is caused.

This issue relates mainly to MV network protection. It is not a safety problem but it is a great harm to the network operator. Since majority of overhead grid faults are cleared by fast autoreclosings, the impact of failing reclosings is significant. Again PV unit is not the most likely one to cause such problems but the aggregate impact of units in the same area can become significant.

6.3.2 Unnecessary protection operations

The DG unit located in a public network can result in unnecessary protection operations. This is not a safety problem, but it causes unnecessary service interruptions to customers, and is thereby an important issue to local network operator.

Unnecessary operations may relate to feeder protection in the case when a fault is located outside the feeder in question. DG units will contribute to the fault with a fault current flowing upwards to the substation and further to the fault point. Since the fault current direction is typically not identified, the protection may operate due to the upstream current. The typical case has been shown in Figure 34.

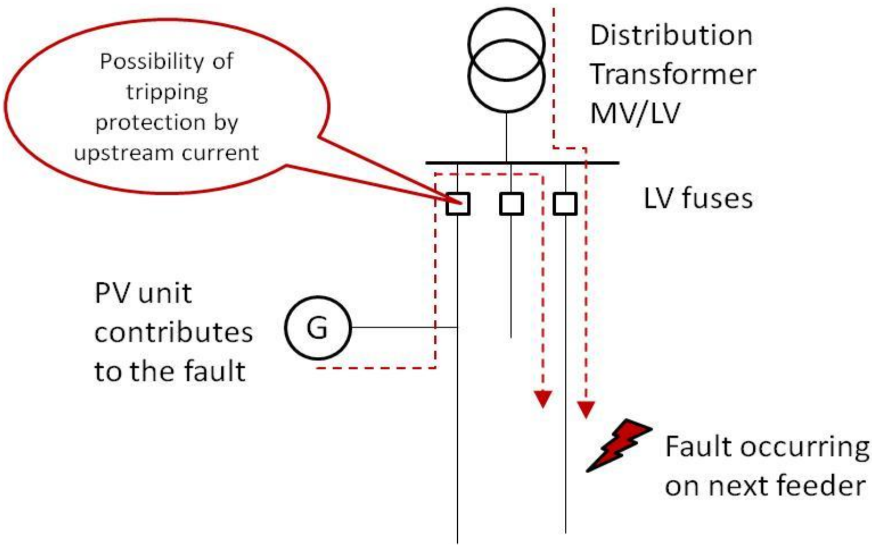

Figure 34. Selectivity problem of possible wrong line separation.

PV units are typically not very problematic in this sense since they are normally not able to feed prolonged fault currents. Thus they are not able to burn feeder fuses or trip relays. However, in case of many units in the same area their impact should be taken into account.

6.3.3 Local safety concerns

In the case of small-scale PV installations, local safety is the most important concern. The units are often installed with simple manners and the protection devices may be lacking or they may have improper settings. The installations are typically not proof-tested before use and sometimes they are not reported to the local network operator.

The major concern relates to islanding situations. Islanded operation means a situation, in which a part of the network remains energized by DG without a connection to the public network. In the case of PV, a single house can form such an island. In the case of multiple PV units in the same area, the island can be formed in the public network. Figure 35 illustrates the different possibilities of island formation. Island can be dangerous for instance in the case of field crews working in the area; they assume to be working on disconnected network. Furthermore, DG is not intended for a maintaining power quality and customer equipment damages are likely if the island remains for a longer period.

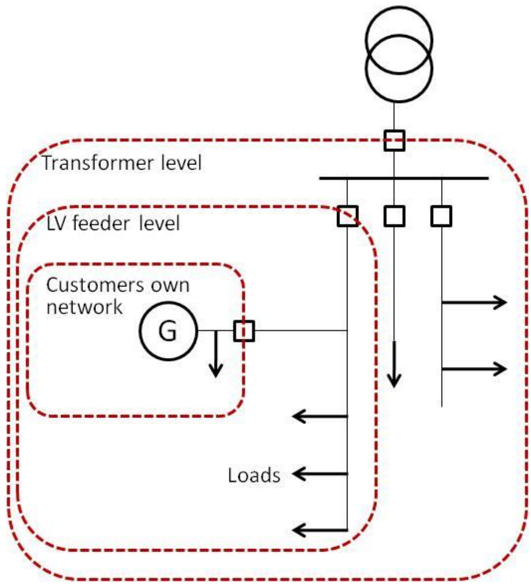

Figure 35. Different possibilities of unintended island forming in LV network.

It must be noted, that above stated refers to unintended islands, which means that the transition to island is not planned. Planned islanded operation is an exciting possibility in the near future. Such island must always be planned and maintained by local network operator who is responsible for safety and power quality in the operation area.

In addition to islanding-related safety, the earlier mentioned problems in which fuse is blown slower or, on the other hand, is blown unnecessarily, can be scaled to the customer's own network as well. Installing PV behind customer's own switchboard may result in totally same results – in smaller scale but still dangerous – as in the public network.

6.3.4 System-level impacts of PV installed in LV networks

As the amount of PV installed in low voltage networks increases, the impacts are evidently getting more visible on higher levels as well – in medium voltage distribution networks and even in transmission networks.

One example of this has been faced in Germany, where a need of modifying the overfrequency protection settings of PV panels has been observed. Until 2011, all PV units installed in LV networks have been set to trip with an overfrequency of 50.2 Hz. This relatively conservative value has been set according to situation in which PV had very minor role on overall power generation. It also reflects the traditional thinking, according to which PV – as well as other forms of DG – has negative impacts on power quality and they should thereby be disconnected when something special occurs in the network. It can also be seen, that disconnecting small amount of PV has been suitable first control action during high frequencies.

With the rapid development of PV, the old setting has become outdated. The amount of installed PV in Germany in 2010 was 17000 MW, whereas for whole Europe more than 25000 MW. The European transmission network system has been dimensioned for losing 3000 MW of generation abruptly, which roughly equals to losing the generation of a large nuclear power plant. With the latest amounts of PV, it is getting more and more possible to lose more than 3000 MW of PV in certain areas. As these PV units are equipped with extremely sensitive 50.2 Hz overfrequency setting, they might be tripped in large masses and even result in blackouts on transmission system level.

Actions are currently taken in order to tackle this problem. The first solution is to set new installations with varying overfrequency limits, for instance between 50.2…50.5 Hz. Further plans are to include PV units in a simple frequency control, in which they would measure the local frequency and reduce their output power when needed. However, there are still open issues with existing PV units. A study (Ecofys 2011) proposes that around 315 000 existing PV units should be retrofitted to avoid large-scale problems.

The 50.2 Hz issue can be considered a classical example of grid impacts of PV or other small-scale DG. Initially the amount is small, hence the impacts are small and they can be neglected in network planning and operation. At the same time, PV generation is considered mainly as a source of possible problems for network operation, thereby it is managed conservatively. In the next phase, the mass increases “silently”, it may be difficult to monitor and follow. Problems are not faced. But once the mass becomes critical, the impacts can be surprising. At this phase, it is often difficult to affect the existing devices and the solutions needed may be expensive and difficult to implement.

One aspect of this issue is that the requirements for small PV units are set on local distribution operator level, but the impacts can be visible on transmission system level. In the future, more collaboration between transmission and distribution network operators will be needed in the area of micro-generation as well.

7. Electrical storages (ES) in Photo Voltaic (PV) systems

A solar energy system can be deployed with or without energy storages depending on the needed functions and performance. Typical feature for the electrical energy storages in an arctic solar system is a requirement to be located inside in room temperature during wintertime. Some type of high temperature battery storage systems like sodium-sulfur battery system can be installed outside. This requirement will increase the solar storage system cost.

Basically the storages for arctic systems are the same types that are used in the other solar systems. Energy storage technologies can be broadly categorized as electrical, electrochemical, mechanical, and thermal storage systems. Suitable storage technology depends on the solar system size, type, and needed system performance. Electrical storages like supercapacitors are not typically used as a PV-system energy storage because of long storage time requirements. However, these short-term storages including also flywheels can be used with longer-term storages to smooth rapid power changes caused by clouds. Supercapacitors can also be used as PV-panel integrated storages. Very large storage systems such as large CAES and pumped hydro power plants are place and location dependent systems and can be considered as a large area or country level bulk power storages rather than PV-system storages. Hydrogen can be used as a chemical energy storage, which energy can be used either in fuel cells or in combustion engines to produce heat and power.

This study describes typical mature and some developing electrical energy storage technologies that are usable with arctic PV-systems. Thermal storages are not included and e.g. new type of solar thermal tower power plants which can include steamed water or molten salt storages are not handled in this study because they are typically installed in high direct normal solar insolation areas and not suitable as arctic solutions today.

7.1 Photovoltaic system categories

Three most typical photovoltaic systems are a small residential PV panel system, a medium size commercial PV panel system, and very large commercial PV power plants. In the following table PV systems are divided in 5 categories according to the size and grid connection types (Table 3).

Table 3. Photovoltaic system categories. (Cleveland 2010), (SEGIS-ES 2008)

Type	Application area	Power	Phase	Connection type
Small residential	Customer site: private houses, summer cottages	< 1 kW	Typically single-phase	Off-grid, typically storage included
Residential	Customer site: private houses	< 10 kW, typical 3 kW	Typically single-phase	Off-grid or grid-tied, without storage or storage-included
Small commercial	Customer site: public buildings, small industrial buildings, community common	10 kW – 50 kW	Three-phase	Grid-tied, without storage or storage-included
Large commercial	Customer site: industrial building area, community common, small PV power plants	50 kW – 100 kW	Three-phase	Grid-tied without storage or storage-included
Very large commercial	Large PV power plants	100 kW – megawatts	Three-phase	Grid-tied typically without storage

7.2 ES technologies for residential systems

Requirements for energy storages in residential systems include low cost, high safety, maintenance free, deep cycle and small footprint. Weight is not a limiting factor for stationary batteries. Today available and typically used technologies are different kinds of lead acid batteries, in smaller amount also nickel-based batteries are used and the latest promising technology is lithium-ion.

7.2.1 Lead acid batteries

Most used lead acid battery previously was open type that needs periodic electrolyte maintenance by adding distilled water. Nowadays there are various types of basic lead acid batteries and the suitability for PV systems depends mainly on the cyclic life performance. So-called SLI (Starting-Lighting-Ignition) batteries can be divided as basic car batteries and truck-batteries. Car type SLI-batteries allow to discharge a high amount of energy in a short time but don't allow deep discharge and are not recommended for PV systems because of very short life time. Stationary batteries, so called Plante-type LA-batteries that are used in UPS-systems are not suitable for PV-systems that typically need high cyclic life. SLI –batteries meant for trucks are better suitable as low cost PV-batteries having acceptable life-time when one uses so called shallow cycling, which does not allow the battery to approach its cutoff voltage. Also Lighting and Leisure type LA-batteries can have an acceptable lifetime with shallow cycling. Semi Traction type batteries that have been developed for golf cars, lawn movers etc. and Traction type batteries developed for e.g. fork lift trucks can also have sufficient life time when shallow cycling is used. Solar type LA-batteries are developed especially for PV-system purposes and have best lifetime in low cost PV-systems.

Nowadays commonly used sealed lead acid (SLA) batteries can be glass matt (AGM) or gel (GEL) technology. Because cells in GEL-batteries are sealed and cannot be re-filled with electrolyte, controlling the rate of charge is very important or the battery will be ruined in a short order. Gel cells use slightly lower charging voltages than flooded cells and thus the set-points for charging equipment have to be adjusted. Absorbed Glass Mat (AGM) batteries are the latest step in the evolution of lead-acid batteries. Instead of using a gel, an AGM uses a fiberglass like separator to hold the electrolyte tied in place. Since they are also sealed, charging has to be controlled carefully or they can be ruined in short order. Gel cells and AGMs require practically no maintenance. Lead acid lifetime is depending on temperature. Every 15 °C increase over 25 °C can reduce their lifetime by one half. Energy density is 50 Wh/l, efficiency 80–90%, lifetime 3–12 years, cyclic lifetime 50–2000 (7000) cycles and temperature area is -25 °C –+60 °C. Examples of Flooded lead acid deep cycle batteries are presented in Figure 36.

Figure 36. Examples of Flooded lead acid deep cycle batteries. [Source: Deka Batteries and Trojan Battery.]

Latest types of lead acid batteries are lead-carbon batteries. One or both electrodes of lead carbon battery can be made from activated carbon as in supercapacitors. The electrode can be made of carbon graphite foam that is covered with lead. As a result of a larger surface (1500 m2/g) the reaction rate is faster, discharge speed is faster, and the weight and size of the battery are smaller (half) those of lead acid battery. Also the capacity in cold circumstances is bigger and corrosion is smaller. E.g. Furukawa Battery (Ultra Battery) and GS Battery (ECO-

R) are manufacturing lead carbon batteries. Examples of the lead carbon battery are presented in Figure 37.

Figure 37. Examples of the lead carbon battery (ECO-R 4V, 70 Ah and Ultra Battery 2V, 200 or 1000 Ah). [Source: GS Battery and Furukawa Electric]

7.2.2 Nickel-based batteries

Nickel Cadmium (NiCd) batteries have good load characteristics; they are simple to use and economically priced. NiCd batteries can be designed for a different speed of charge. They have a memory effect that makes them not suitable for most PV-systems even if they were earlier very common battery types in solar lighting systems. Nickel metal hydride (NiMH) provides 30% more capacity over a standard NiCd. The positive electrode of the NiMH battery is nickel hydroxide. The active material for the negative electrode in the NiMH battery is actually hydrogen and the hydrogen ions (protons) are stored in the metal hydride structure that also serves as an electrode. The NiMH is affected by memory to a lesser extent than the NiCd and periodic exercise cycles need to be done less often. Ni-based batteries have quite high self-discharge, about 1-5% decrease of their charge per day. Because of low toxic metals content, the NiMH is labeled "environmentally friendly" and NiMH batteries are typically 100% recyclable. NiMH battery (e.g. Saft NHE) operating temperature is –20 °C – +40 °C, cyclic lifetime ~2000 cycles. Examples of nickel batteries are presented in Figure 38.

Figure 38. Ni-CD (Sunica plus) Ni-MH (NHE) battery storage for PV applications. [Source: Saft]

7.2.3 Lithium ion batteries

Lithium is a very reactive material and lithium cells can produce remarkable high voltage (Li-cobalt 3.2–3.6 V, Li-phosphate 3.2–3.3 V, Li-manganese 3.7–3.8 V, Li-nickel oxide 4.2 V) compared to 1.2 volts of Ni-based batteries. Lithium-ion batteries have low discharge compared to other rechargeable batteries but aging process starts already on a storage shelf. Lithium-ion batteries offer energy densities of 100–150 Wh/kg with charge/discharge efficiencies of 90–100%. Cyclic lifetime is long, depending on a battery type from 3000 cycles to 16000 full cycles and even 250000 partial cycles. Lithium batteries have no memory effect. Lithium batteries are very sensitive to overvoltage and need also temperature and current control as well as deep discharge control and a battery balancing system for larger series connected systems. Lithium-ion batteries should be stored in low temperature (0–°25 C) rather at 40% than at 100% charge to decrease ageing process. Most lithium-ion battery electrolytes freeze at approximately -40 °C. New lithium battery system solutions include also an intelligent control system (Figure 39) and are packed in the standard lead acid Battery Council International (BCI) format sizes. Lithium ion cells cannot tolerate overcharging and balancing circuits are needed to prevent overcharging cells but ensure charging all cells to the similar voltage level. Manufacturers for lithium-ion batteries include Saft, A123, Altairnano, European batteries and International batteries.

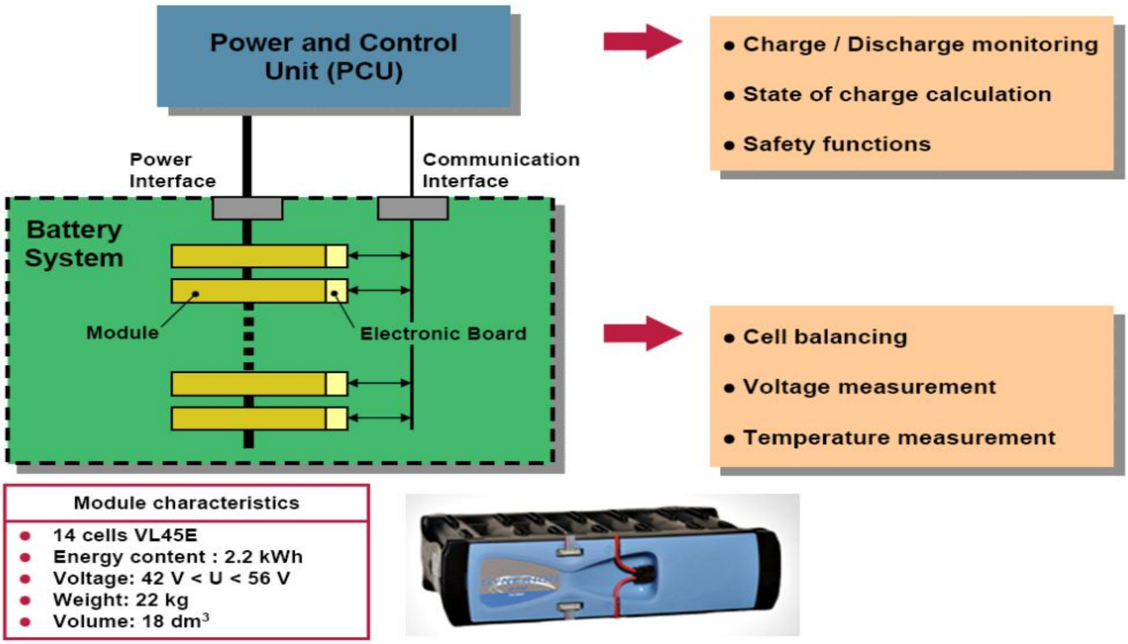

Figure 39. An example of the li-ion (lithium nickel oxide) battery solution for residential PV system. [Source: Saft]

7.3 ES technologies for commercial systems

Commercial PV-systems are typically 3-phase grid tied systems but could be also 3-phase islanded systems or 3-phase systems that can work also islanded. Lead acid, lead carbon, NiMH, and lithium-ion battery technologies are used also in larger grid-connected PV-systems. Typically large over 100 kW systems are installed in storage containers including power electronics, control systems, and even transformers. An example is Saft 200 kW li-ion system (Figure 40). Another example is Altairnano's 2 MW Alti-ESS two-container system that can be used with large PV-power plants (Figure 41). ALTI-ESS power systems include the flexible 1MW/250kWh battery platform, including battery management system, solid-state inverter, power electronics, and programmable logic controllers. AC voltage is 480 VAC, response time < 20ms, storage temperature -40 °C to +55 °C, roundtrip efficiency > 86% at full power. Cycle life is 12,000 + cycles and calendar life is 15-year.

Other technologies for larger PV-systems are flow batteries (e.g. ZnBr or Vanadium-Redox), sodium based batteries (NaS, ZEBRA, Durathon and aqueous sodium ion) and in future also small compressed air storage systems. Bulk storage systems such as larger compressed air plants and pumped hydro power plants are place depending and can be considered rather transmission grid connected storages that serve large area grid control.

Figure 40. An example of the medium size Li-ion (200 kW, 600 kWh, 700 V) storage container. [Source: SAFT]

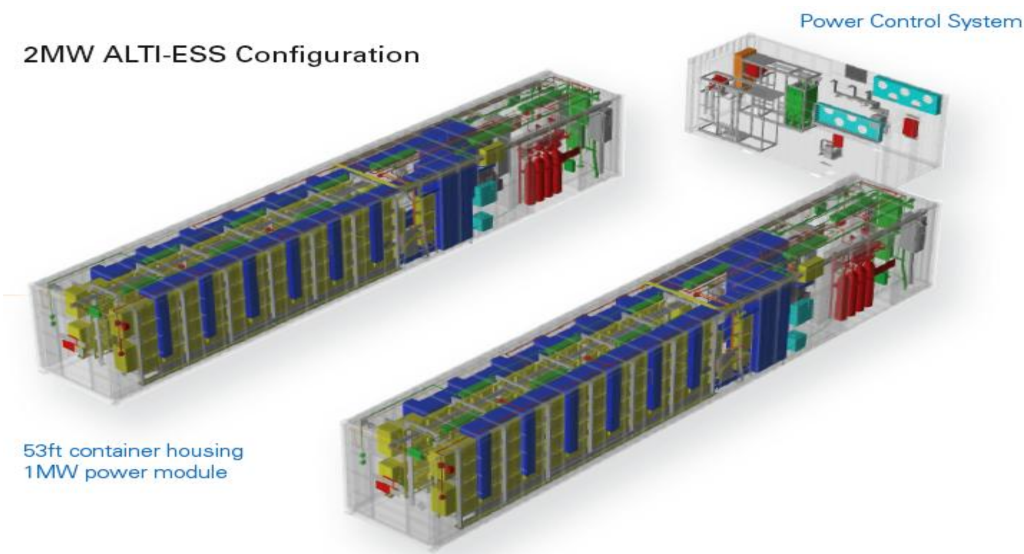

Figure 41.Example of the large 2 MW (2x1MW/250kWh) Li-ion battery container system. [Source: Altairnano]

7.3.1 ZnBr batteries

Exxon developed ZnBr battery in the early 1970's. ZnBr battery consists of a zinc negative electrode and a bromide positive electrode separated by a micro porous separator. An aqueous solution of zinc/bromide is circulated through the two compartments of the cell from two separate reservoirs. Nominal cell voltage is 1.8 V, 100% depth of discharge capability on a daily basis; energy density is 75–85 Wh/kg, and cyclic life > 2000 cycles, and round trip efficiency 70–75%. Premium Power produces Zinc flow battery Zinc-Flow 45 that is a regenerative fuel cell. Rated output is 0–30 kW, peak efficiency 73% and capacity is 380, 938 or 1875 Ah.

7.3.2 Vanadium redox batteries

Vanadium redox flow battery is based on the use of solubility of vanadium in four different oxidation states in sulphuric acid. The system consists of two electrolyte tanks, containing active vanadium species in different oxidation states. Output power and energy storage capacity are independent. Energy storage capacity is determined by the concentration and volume of the electrolyte. The output power depends on the number of flow cells (stacks) and the surface area of the electrodes. VRB operates at normal temperature. Nominal cell voltage is 1.15–1.55 V, energy density is 15–25 Wh/l, cyclic life >10000 cycles, and round trip efficiency 75–80%. Prudent Energy manufactures VRB battery systems of different sizes from kW-class to MW-class.

7.3.3 NaS Batteries

NaS battery consists of sulphur at positive electrode, sodium at negative electrode as active materials, and Beta alumina of sodium ion conductive ceramic, which separates both electrodes. NaS battery has 151 kWh/m^3 energy density and approximately 2V voltage at about 260 to 360 °C working temperature. NaS battery has 15-year service life and high cycle life (2500 cycles at 100% DOD, 4500 at 90%, and 6500 at 65%).A Japanese company NGK Insulators LTD has been the only NaS battery manufacturer with production capacity 150 MW/year in 2010. At present NGK places top priority on safety measures to prevent fire of battery systems. POSCO in Korea and Eagle Picher Technologies have also informed about developing large capacity NaS batteries. NaS batteries for PV system output power smoothing is presented in figures 42 and 43.

Figure 42. NaS system stabilizating intermittent renewable energy. [Source NGK]

Figure 43.1.5 MW NaS alongside 5 MW Solar PV Array in Japan. [Source NGK]

7.3.4 ZEBRA batteries

ZEBRA batteries are based on sodium nickel chloride technology. Sodium/nickel chloride is produced on a commercial scale in Switzerland by MES-DEA (now

FIAMM SoNick). The battery has to be maintained at an internal operating temperature of between 270˚C and 350˚C for efficient operation.

ZEBRA batteries are produced as 24–1000 V, 2–50 kWh systems. Batteries are practically maintenance free. Weight is around 40% of lead acid battery weight. ZEBRA Battery technology has proven calendar life of more than 10 years and cycle life of 1000 nameplate cycles dependent on operating parameters. A diagram of ZEBRA battery is presented in Figure 44.

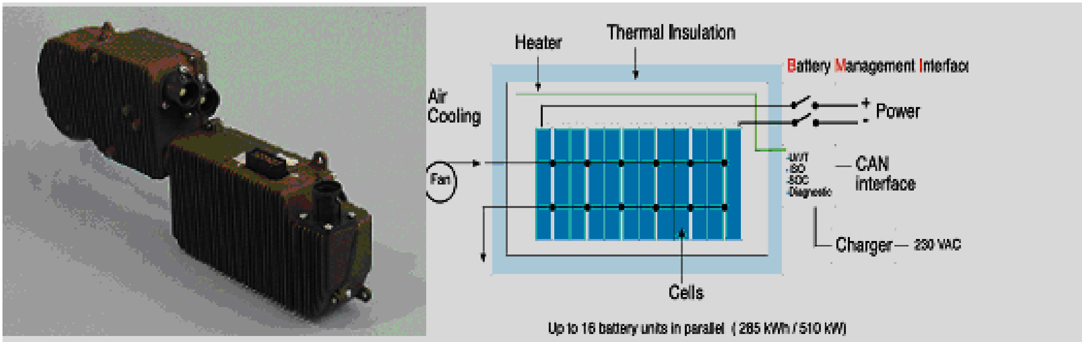

Figure 44. ZEBRA-battery and battery block diagram. [Source: FZ Sonic]

7.3.5 Durathon Batteries

GE Transportation has launched molten salt battery by the name Durathon in 2010. GE’s sodium-metal-halide battery consists of a nickel chloride cathode, a beta alumina separator, and a liquid sodium anode. An integral battery management system is installed on all battery modules and controls charge/discharge, monitors battery parameters, provides battery protection, and passes information to the outside world through common Modbus protocol.

7.3.6 Isothermal compressed air storage

Today there are two Compressed Air Energy Storage (CAES) plants: one in Hunfort Germany (320 MW, 1978) and other in McIntosh, USA (since 1991). There are several efforts to develop smaller higher efficiency compressed air systems that do not need natural gas as fuel. That is studied e.g. in the EU project Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) and by a study presented by General Electric and RWE in 2008.

Smaller compressed air systems could also be a possible local PV-storage. Isothermal compressed air system ICAES (Figure 45) uses electrical energy to compress air near-isothermally, stores it aboveground in commercial gas storage facilities, and expands it near-isothermally to generate electricity using no fossil fuels. SustainX develops ICAES. The systems has a higher isothermal efficiency (94.9%) compared an adiabatic technique (54%). New products (e.g. 1 MW system) are planned to be brought to market in 2012.

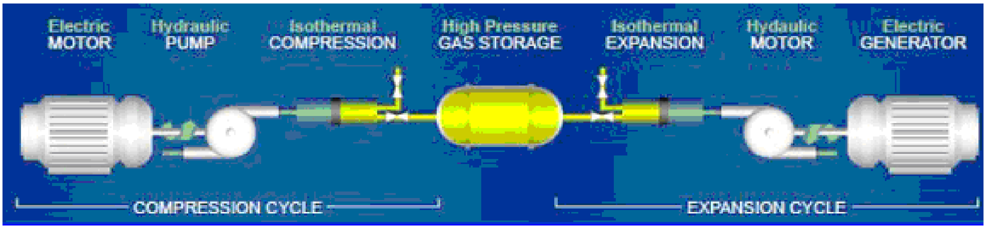

Figure 45. Isothermal compressed-air energy storage using hydraulics. [Source: SustainX]

7.3.7 Hydrogen as energy storage

Hydrogen is one of the cleanest fuels. A fuel cell operating with pure hydrogen and oxygen produces only water and heat as reaction products. Hydrogen can be manufactured with electrolysis with minimal emissions from water. Hydrogen can be stored as compressed gas, as liquid or absorbing it to metals or carbon structures. Also converting hydrogen to lower energy fuel like methane can be seen as a hydrogen storage but also as a two stage burning process. Hydrogen storage requires expensive infrastructure but in cases when consumption does not cover all available production from e.g. wind or solar power, price of electricity becomes negative in balancing power markets and hydrogen could be one storage option at some point in time.When hydrogen is considered as storage for solar energy, mass density of the storage is not important. More important is the volumetric density; how much space is needed for the storage. Highest volumetric energy densities for hydrogen storages are in Ethanol, Methanol and metal hydride storages (Sørensen 2005). Storage energy consumption of 15MJ/kg of hydrogen was presented (Kit Heung 2003) for metal hydride storage (waste heat is used for desorption). This equals 89.6 % efficiency related to heat of combustion for hydrogen (120 MJ/kg). In a similar way calculated storage efficiency of compressed hydrogen storage to 34.45 MPa (340 atm) was 70% and for liquid storage 65%. When hydrogen storage is compared with batteries, electric efficiency of fuel cell or combustion engine has to be taken into account and also the value for the heat produced in the conversion process.

Metal hydrides are one of the more promising options for stationary hydrogen storages due good storage efficiencies and high volumetric energy density. Of course price of metals can tend to limit possibilities for large systems and overall system electric efficiency can be low because of losses from fuel cell or from combustion engine.

7.4 Summary of energy storage technologies

This chapter describes some typical electrical energy storage solutions suitable to be used with residential and commercial PV-systems. All technologies are suitable also for arctic circumstances when placed in room temperature inside the buildings or special heated containers. Typically rechargeable chemical battery capacity decreases remarkably at a low temperature when chemical reactions proceed more slowly although the self-discharging is slower, too. However, there are some battery types that are specially manufactured to work in cold environments e.g. some NiMH batteries with working temperature range of -40 °C…+85 °C.

Safety issues are very important especially for residential systems and because of that the newest low maintenance types of basic mature storage technologies like AGM or lead acid batteries are still mostly used. Newest lithium-ion battery types like Lithium-iron-phosphate batteries are the new coming technology also for PV-systems especially when they are packed by a battery manufacturer as a combined package with safety circuits, and thermal and communication management systems. Lithium battery technology is in a fast developing phase and new innovations using e.g. nanomaterials can increase capacity and charging speed remarkably in the near future.

A new larger storage technology could be adiabatic compressed air storage that is now in the development phase. However, all these storage systems are still rather power than energy storages because of self-discharge and short discharge time (max. hours rather than days). They cannot solve seasonal storage requirements (with storage time of several months) needed in efficient arctic PV-systems. This concerns also large compressed air and hydro power plants. In the following table (Table 4) strengths and weaknesses of different electrical energy storage types are described.

Table 4. Strengths and weaknesses of different electrical energy storages in PV-systems.

PV system type	**Storage type**	**Strengths**	**Weaknesses**
Residential < 10 kW, typical 3 kW (small residential < 1kW)	Lead Acid (AGM, GEL, Solar, Truck, Traction, Semitraction, Lighting and leisure types)	Mature, widely used, cost efficient Low self-discharge (2–3%/month) Small service cost (closed LA) Recharge ability (90%) New techno.: Lead-carbon	Low energy density (25–50 Wh/kg) Environmental hazard (Lb) Narrow temperature area Low efficiency (75–85%) Low cyclic lifetime ~2000 cycles
	NiMH	Mature, suitable for high power applications, Low maintenance, Wide operating temp. range (-20 ºC -+60 ºC)	High rate of self-discharge Low cyclic lifetime ~2000 cycles
	Li-ion with battery control and management system	Mature/ fast developing High energy- and power density (120–160 Wh/kg) Light, no memory effect Low self-discharge (5%/m.) Long cyclic life (3000–5000– 16000 cycles), long service life Li-oxides and salts can be recycled	Needs heat control High investment cost Needs battery cell balancing and protection High nominal cell voltage 3.2–4.2V
Commercial ≤ 100 kW Typically grid-connected and 3-phase systems	Most widely used: LA, NiMH, Li-ion with DC-AC converter	See above residential	See above residential
	ZnBr flow batteries	High energy density (75–85 Wh/kg) Cyclic life (> 2000 cycles) Fast response time	Low efficiency (70–75%) No small systems, cost Complex construction Few manufacturers
	Vanadium Redox flow batteries	Cyclic life (> 10000 cycles) Fast response time Small service cost No self-discharge	Low energy density (25–35 Wh/kg) Low efficiency (65-75%) Cost, complex construction Few manufacturers
Very large commercial 100 kW–megawatts	Most widely used: LA, NiMH, Li-ion with DC-AC converter	See above residential	See above residential
	NaS (mature)	High efficiency (89–92%) High cyclic life (~2500 cycles) High energy density (150–200 Wh/kg) No memory effect, No selfdischarge (Low capital cost) Suitable for MW size systems	High work temp. (300–350 °C) Few manufacturers (NGK Insulators, GE Energy plans to start production in 2011), Current safety issues (fire accident)
	AA-CAES	High isothermal efficiency Above ground systems	Early phase developing No commercial products

8. Future outlook for solar energy

8.1 Availability of raw materials and production capacity

Silicon is the most common base material in solar cells. Resource capacity of silicon on earth is practically limitless but there have been shortages in purifying capacity. Silicon for solar panels comes also partly from electronics industry where quality demands are higher compared to solar energy production. Lower quality part of the silicon is sold to PV industry. Currently demand for polysilicon is higher in PV sector compared to whole electronics industry. This is good for PV industry because they no longer have to depend on electronics industry to supply them material and new production capacity enables cheaper material costs aimed for the demands of PV industry (DOE 2010).

Some PV technologies however do not require polysilicon at all. These technologies include thin film solar panels such as amorphous silicon cells and dye-desensitised cells. Market share of non polysilicon technologies is projected to reach between 16 and 32% in year 2012. Thin film panels usually need small amounts of rare materials such as indium, gallium, and tellurium. This rare material demand is approximated to limit the maximum production for some thin film panels (Grama & Bradford 2008). Some have been concerned that growing demand in China together with the fact that China has a large part of rare material reserves for solar panels, could raise the prices for thin film cells in the future.

Concentrated solar power (CSP) uses steel in structures which makes profitability of CSP dependant on steel prices. Steel prices depend strongly of economic growth of emerging countries. Currently there are not many companies involved in manufacturing CSP components, and problems with single suppliers can generate problems for part availability (DOE 2010). A salt storage located in the tower, where mirrors of CPS are facing, is a new construction to store solar energy in heat mode based on phase change of the salt. The storage can give heat to steam generation during dark period in night and the power plant can generate power through the day.

8.2 Dependency of financial support in the Nordic region

Large scale use of solar energy for power generation still demands financial support in the Nordic region. Use of solar energy for heating can already produce savings for heating costs. Also the point for solar power generation to be economically reasonable for residential power generation is not too far.

8.2.1 Comparison to the financial support in Germany

Germany has been considered as the most active country in the area of promoting renewable generation with financial support. The history of feed-in tariffs dates back to year 1990, when the first law of feeding energy to the grid was stated. This law boosted the amount of wind power in Germany, but it was not able to make more expensive forms of production such as PV viable. The feed-in tariff system was completely changed in 2000 as a new law was set. The major improvement was that guaranteed feed-in tariffs were now defined according to the primary energy resource. Size of the unit was also taken into account in the tariff definition. The duration of the tariffs was extended to 20 years and the annually descending nature of tariff was introduced. After that, some adjustments have been made to the law. The tariffs have been checked annually. Figure 46 presents the evolution of feed-in tariffs for roof-mounted PV systems in Germany.

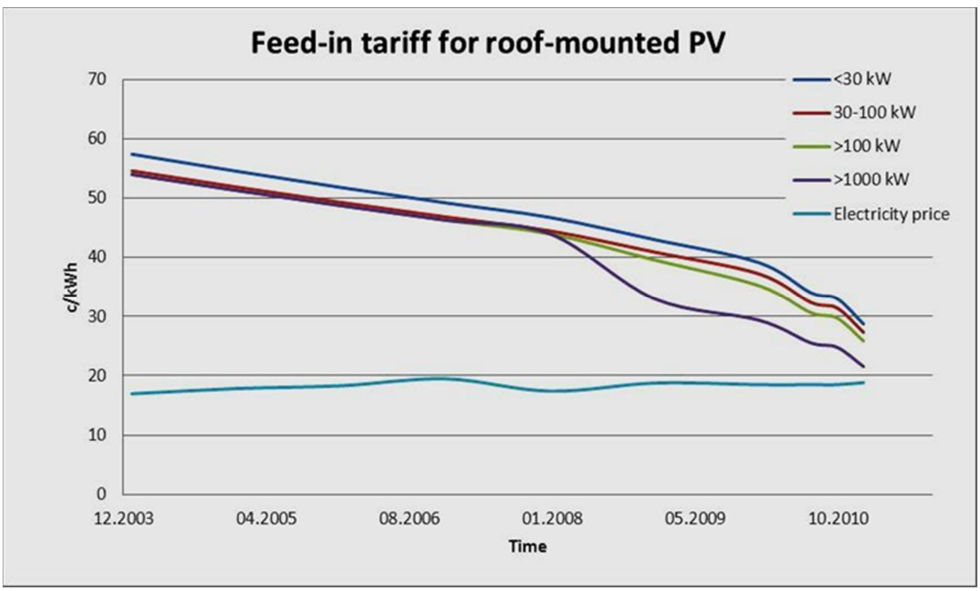

Figure 46. Feed-in tariff for roof-mounted PV in Germany.

As it can be seen, the feed-in tariffs have been reduced during latest years and price for production is starting to approach typical customer electricity prices. At the same, the PV equipment prices are decreasing and the amounts of installed PV are increasing rapidly. This kind of development will lead to the situation in which PV is viable also without support, which is a long-term objective of feed-in tariff systems. It can be said that Germany has succeeded very well in promoting small scale PV – although it has had certain impacts on customer electricity pricing. As an example we can look at year 2004, when Germany had just installed first GW of PV systems. Depending on the unit size, roof-mounted PV panels were guaranteed around 55 c/kWh whereas customers paid around 17 c/kWh for their own consumption. While the generation can be sold separately from own consumption, this surely is an attractive setting for installing PV panels on roofs. Comparing this to current situation in Finland, customer pays around 10 c/kWh for consumed electricity and PV generation can be mainly used for reducing own consumption. In other words, 10 c/kWh can be considered as the PV tariff. There is a huge difference when taking into account differences in equipment prices and solar resources.

8.2.2 PV profitability simulation for small household power system

Profitability of photovoltaic power generation can be approximated by calculating net present cost of the household energy usage and investment costs. HOMER® is a hybrid power system optimisation program the development of which was started by US Department of Energy in 1992. The program bases comparisons mainly on economics but regulation can be given to emissions and renewable fraction. Program can be used to optimise system and operation hourly with given information and restrictions. Version 2.68 was used for solar energy profitability inspections in this study. Calculations are made in US dollars.

Inspected house

Yearly energy need: 5621 kWh (small house, no electric heating)
Location: Tampere, Finland.
Daily load profile used is presented in Figure 47.

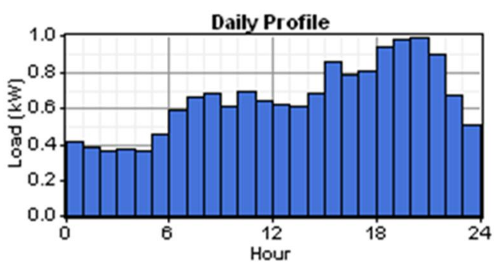

Figure 47. Daily electric load profile for small house with no electric heating.

Economic inputs and constraints

Annual interest rate: 4.5 %

Inspecting period: 20 years

Minimum renewable fraction options: 0, 80% (part that is required to be supplied by PV-panels).

Environmental inputs

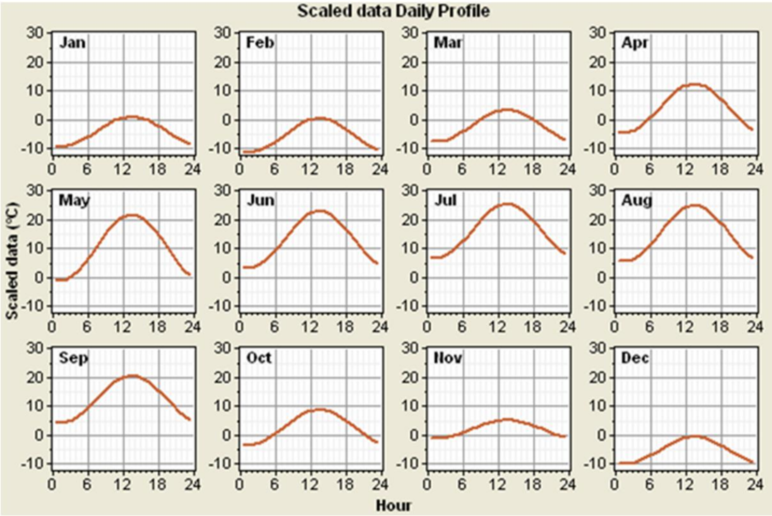

Figure 48. Average monthly temperatures (affects PV-panel efficiency).

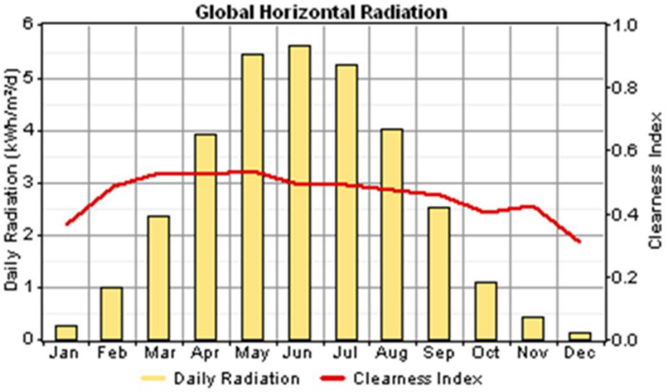

Figure 49. Monthly solar irradiation and clearness index.

Clearness index gives a fraction of solar radiation which arrives through the atmosphere to earth surface.

PV-inputs

Parameter inputs for PV system used in simulation are presented in Figure 50 and grid inverter inputs in Figure 51.

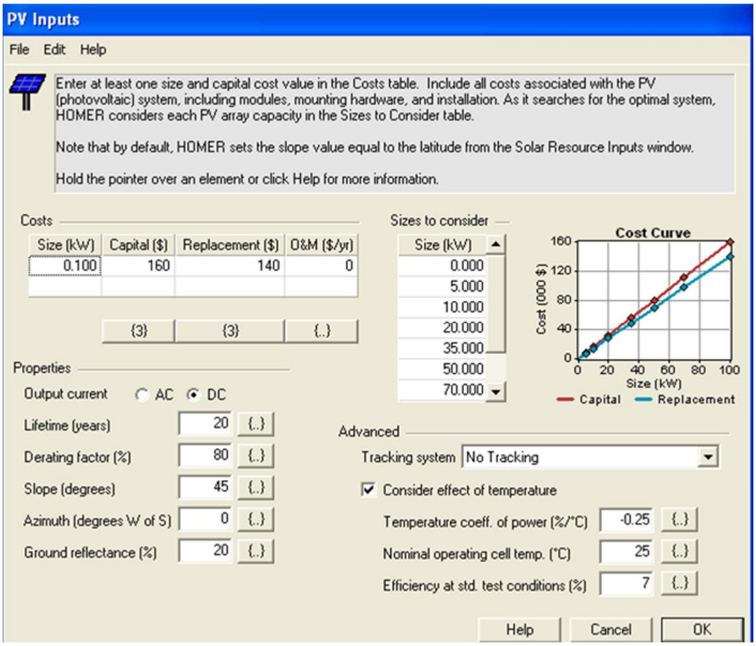

Figure 50. PV system inputs.

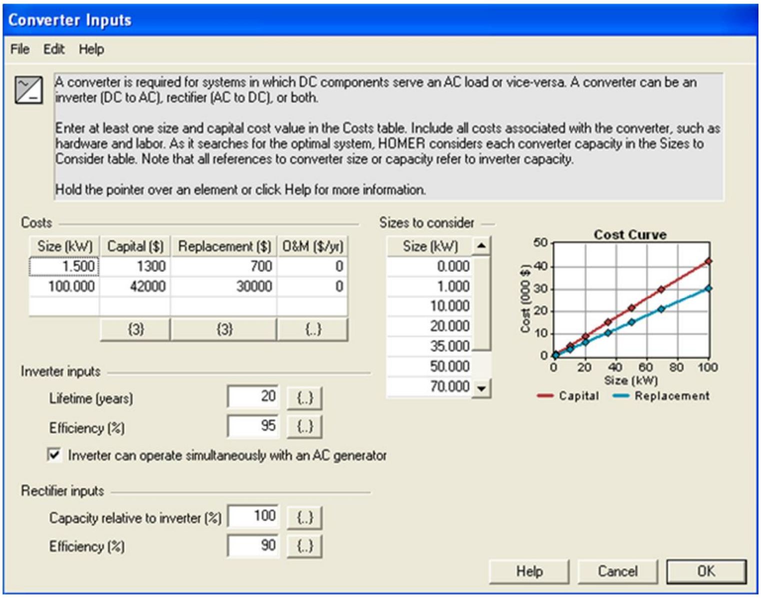

Figure 51. Grid inverter inputs.

Case 1. Power sold to the grid

In this case, all production is sold to the grid with price which is total electricity purchase price subtracted with 0.08$/kWh to take into account transmission costs and feed-in charge. Figure 52 displays how the optimum system depends on electricity price (sell back price is 0.08$/kWh lower) and on capital costs of the PV-panels system.

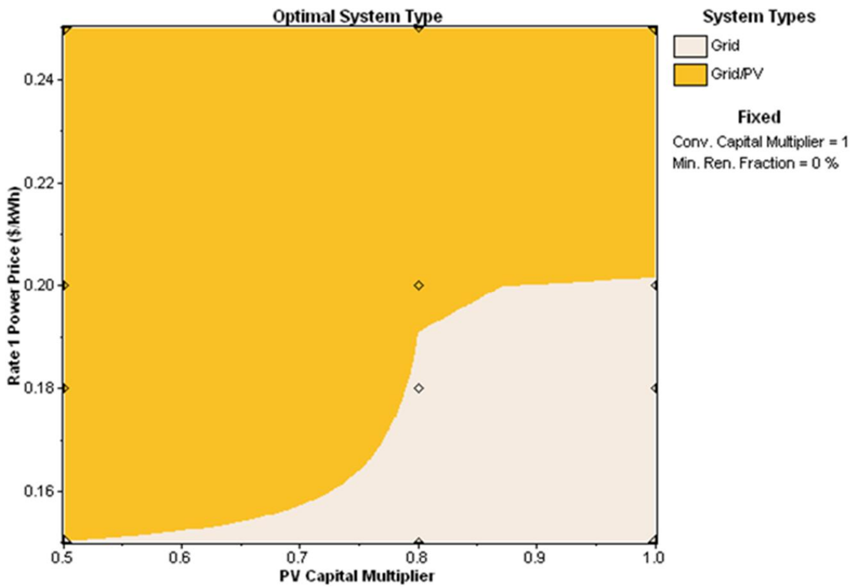

Figure 52. Optimum system type as function of electricity price and PV-panel price multiplier (1.0 equals 1.6$/W).

In Finland the price of electricity is now around 0.08€ /kWh for energy and for transmission 0.056€ /kWh. This equals about 0.195 $/kWh with EUR/USD at 1.44. Profitability limit using this model is fairly close to this level, around 0.21$/kWh if PV price remains at 1.6$/kW.

Case 2. Yearly net metering (not legal in Finland)

Net metering means that production of PV system is subtracted periodically from the consumption and customer pays only for remaining part. Typically there is no compensation for net production and optimum is to have a production, which covers just the own consumption over the period. displays optimum system as a function of energy price and PV-price.

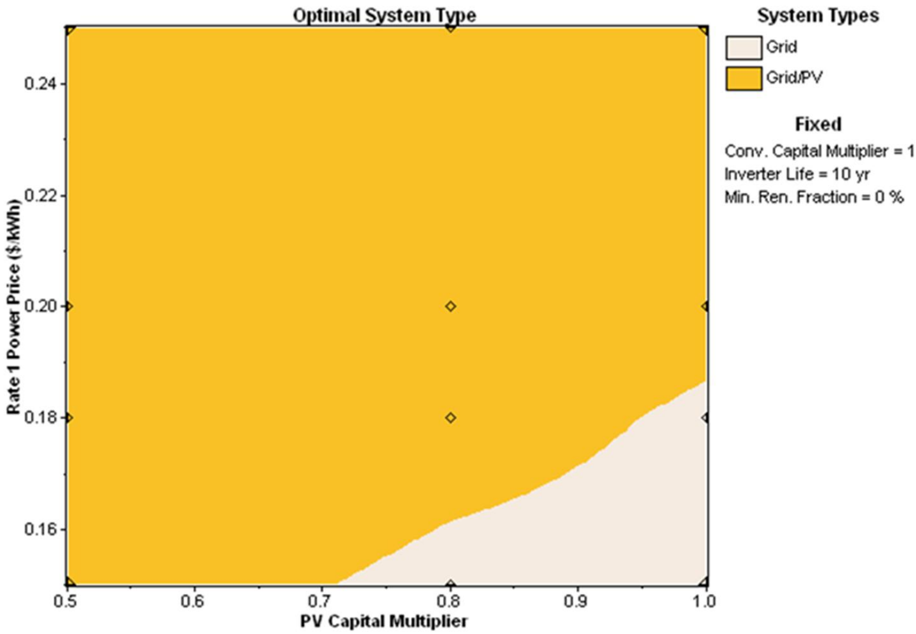

Figure 53. Optimum system in net metering as a function of energy and PV price (1.0 equals 1.6$/W).

As production now refunds consumption, equal price curve is more linear when compared to where production was sold to the grid. Additional difference is that net metering does not direct to large overcapacities to make more profit, because maximum benefit comes when production covers own yearly consumption. This can be seen as benefit for the grids because large excess production can generate problems for the grid operator. Solar production is concentrated to summer months in Nordic region, which of course means that production is over the consumption in summer months and under in winter months. This is problematic, because the power company would be taking cheap summer energy from producer and giving same amount more valuable winter energy in return. This support model would be profitable for a PV system owner in the example case with current market price.

Shorter metering period could ease the price difference problem. Also if actual metering would be done two ways and billing with net sum, the measured energy supplied to grid can be credited to production capacity of main electricity supplier to cover up at the loss of sales from customer with own production. The supplier can possibly also get better price for solar power and cover the losses entirely.

Case 3. No compensation on power feeding

Because it is hard to get buyer for electricity from a small solar energy system, excess energy is given free to grid in some cases. In this situation, the only way to improve economics of this kind of arrangement is to try to match own consumption to PV production. Matching consumption has to be made with energy storage because fluctuating power production of solar panel is not usable with common appliances. For this reason lead acid battery option has been given to the program. Battery capacity was 200Ah and price 400$. However the optimisation did not result in recommending use of any batteries due to high costs. displays optimum system as a function of energy price and PV-price.

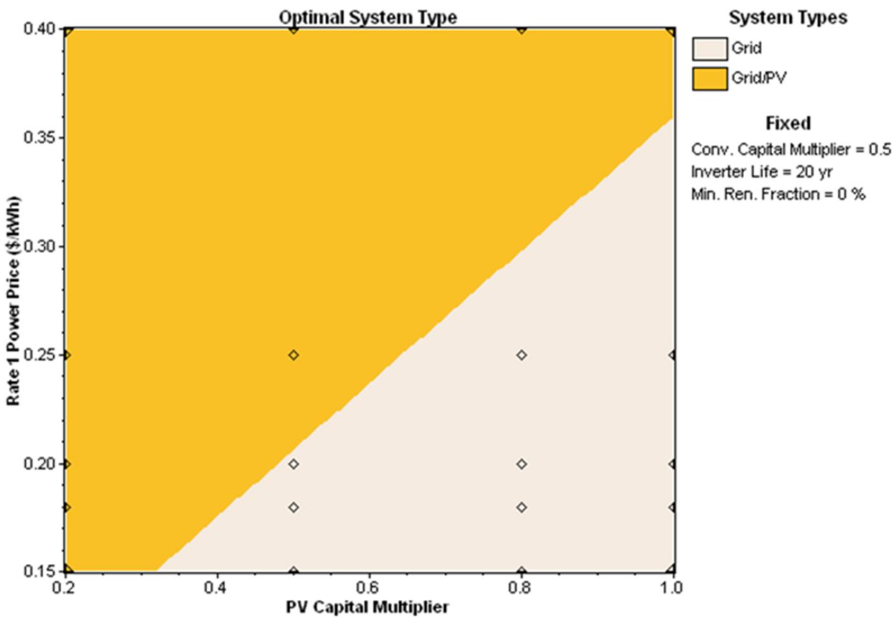

Figure 54. Optimum system in case where there is no compensation on power feeding.

The shape of the figure is similar to that in net metering, but profitability of a PV system comes with much higher electricity prices.

8.3 Life cycle CO_2 emissions of PV panels

Life cycle analysis can be used to evaluate total environmental impact of technology across the lifetime of the system. International panel on climate change (IPCC) has released “Special report on Renewable Energy Sources and Climate Change Mitigation” (IPCC 2011). Figure 56 displays how IPCC estimates life cycle emissions for different production types. Emission values in the figure are based on numerous sources collected by IPCC and the average of each production type is marked with a black line.

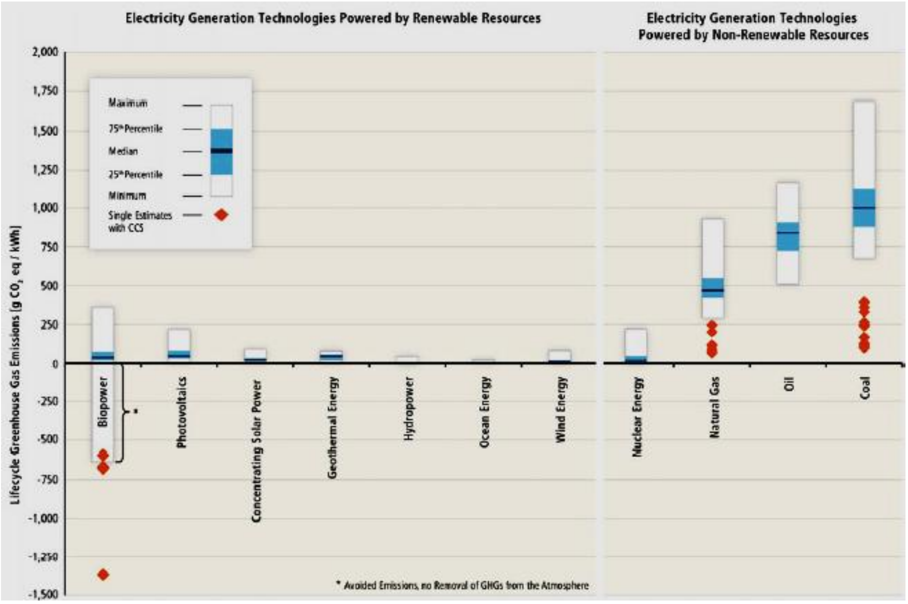

Figure 55. Estimates of life cycle CO_2 eq / kWh of electricity. (IPCC 2011)

It can be seen that solar energy technology offers good reduction to emissions compared to fossil fuel based production. More specific estimates for panels produced and installed in Europe are presented in Figure 56 (Vasilis & Hyung 2007).

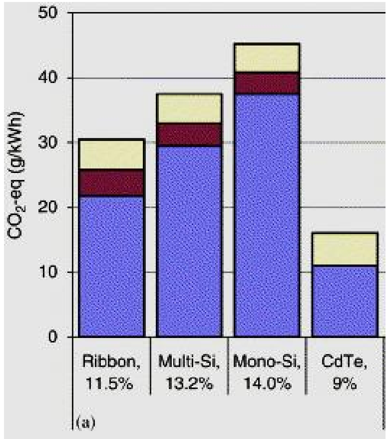

Figure 56. Life cycle emissions for PV panel types in Europe with 1700 kWh/m2/year irradiation, efficiencies of the panels are marked under type. (Vasilis & Hyung 2007)

CdTe thin film panel type is estimated to have the smallest life cycle emissions which are related to low manufacturing emissions and not efficiency of the panel type. Amorphous silicon is also estimated to have relatively small life cycle emissions according to IPCC report.

Life cycle emissions of solar panels have an inverse relation to irradiation conditions. For this reason results presented in previous figures cannot be used straight for lifecycle analysis in specific installation locations. Temperature also affects PV panel efficiency but this relation can be excluded in rough estimations. Lifecycle emissions for PV installation for Finland can roughly be estimated by taking the values calculated in (Vasilis & Hyung 2007) and scaling emissions with reduction of average yearly irradiation. It should be noted that this will likely give slightly higher life time emissions because of lower temperature at lower irradiation countries but also because PV panels are likely to last bit longer in years because lower irradiation puts less stress to panels. Also higher transportation emissions to Finland will counteract this somewhat.

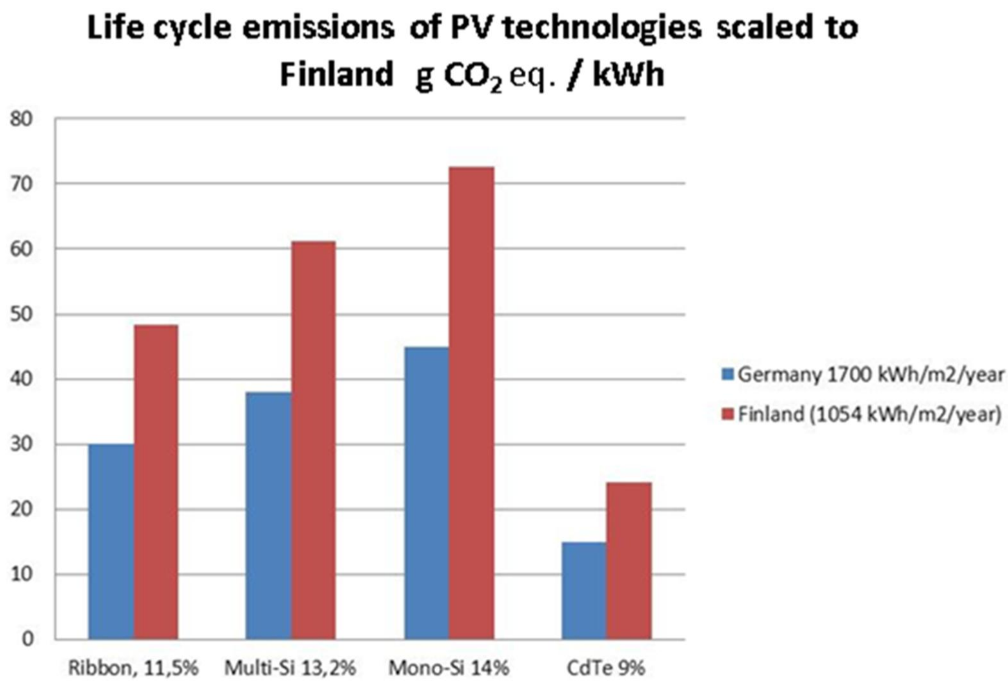

Figure 57. Life cycle emissions of PV technologies scaled from (Vasilis & Hyung 2007) to irradiation of 1054 kWh/m2/year.

It should be noted that an irradiation amount of 1700 kWh/m^2/year is close to the maximum irradiation available in southern Germany. If the values are scaled to average irradiation in Germany of 1157 kWh/m^2/year (EC 2008), the differemce is very small as presented in Figure 58.

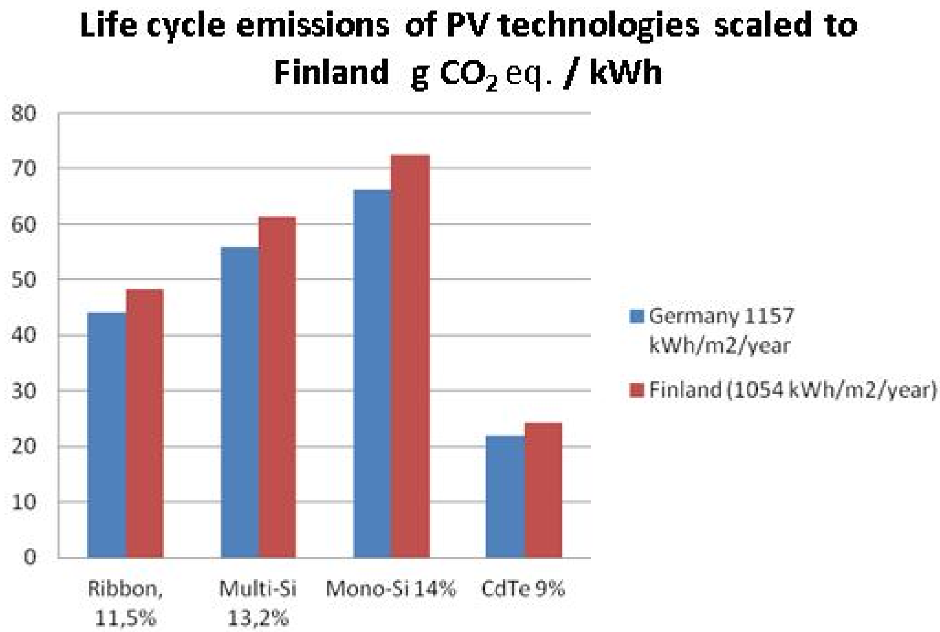

Figure 58. Life cycle emissions of PV technologies scaled from (Vasilis & Hyung 2007) to Germany average of 1157 kWh/m2/year (EC 2008), and to Finnish irradiation of 1054 kWh/m2/year.

Simplified analysis shows that solar panels offer good possibilities to reduce life cycle emission of electricity production also in Finland. Of course the price of PV panels is still a bit too high, but there are no environmental facts that would advise not to use PV panels in Northern Europe.

9. Conclusions

Use of solar energy in Northern Europe is lower than the difference in irradiation conditions or equivalent life cycle CO_2 emissions compared to Central Europe would suggest. The basic reason is lower or non-existent financial support for solar energy and belief that there is no use in using solar energy in Northern Europe. Also notably higher market prices for solar panels in Finland compared to US or Germany affects panel sales here. However, if solar panel prices continue to decline, support for PV system might not be even needed. Better knowledge for the common people about benefits and the difference between Finnish and global market prices could then be adequate.

Solar CHP is demanding but interesting opportunity. There are some solar CHP units in Northern Europe, but in most cases heat collectors and PV panels are installed as separate systems. Due to the fact that there are not many operating solar CHP systems and because there has not been much development in high temperature PV cells, solar CHP has still a lot to be researched so that we can take full benefit of the possibility.

Interesting PV cell types in the future will be multi-junction, concentrated, thin-film and organic solar cells. An interesting feature is also to enlarge utilisation spectrum of light into infrared area. Crystalline silicon has nowadays a market share of more than 90% and it is expected to continue in top to the middle or end of 2020.

Storage systems are still rather power than energy storages because of self-discharge and short discharge time. They cannot solve seasonal storage requirements needed in efficient arctic PV-systems.

PV panels among other types of distributed generation introduce a challenge to electric grid and management of energy balance. Increasing number of PV panels in grid have made reliable protection challenging. And even as protection is sufficient now, old rules might have to be changed like with frequency protection limits. As the amount of PV generation increases, it becomes more and more significant for the stability of the whole power system. Thereby the support of PV units cannot be lost too easily. On the other hand, safety must be assured in all cases. And just like with wind power, solar energy needs balancing power or storages. Solar energy can be seen as more difficult to control because solar irradiation in different parts of the grid tends to rise and to decline in same phase more than wind production which can be more local phenomenon. On the other hand solar production is easier to predict and therefore to prepare for it.

In order to prepare for massive amounts of PV installations, development needs can be seen especially in the areas of network planning systems, modelling, and network simulation tools. Research parties should be able to study the related impacts on a detailed level. Competence on power electronic devices and DC applications is especially important in this sense. Models of different PV cell types, converters, storages etc. need to be built. Network operators should be able to assess the impacts of PV units as a part of their normal network planning processes.

For grid operator purposes, performing detailed simulations is often not suitable. Even the accuracy requirement is lower as long as the planning tools give correct indications on necessary actions. Thereby, for planning tool development certain simplifications must be made to make the calculations more useful. Accurate simulations performed by research parties serve as a basis for making the correct simplifications.

More generally, the arctic perspective of PV applications could be a strength of the Finnish research parties. Many institutions European-wide are performing testing on PV cells and related devices. These may be done in laboratory or as long-term outdoor tests. However, the tests performed with extremely cold climates or with snow and ice seem to be rare at the moment.

References

ABB sol 2011. Press release about ABB PV plant in Pitäjänmäki. Available at: http://www.abb.com/cawp/seitp202/1abf6e2cb6f0b41ec1257744002d622f.aspx

Absolicon 2011. Picture of solar CHP system Absolicon x10. Available at: http://www.absolicon.com

Andasol 2011. Andasol solar power plant animation. Solar millennium AG. Available at: http://www.solarmillennium.de/upload/Animationen/andasol_blue_engl.swf

Berginc, M., Krasovec, U., Jankovec, M. Topic, M. 2007. ”The effect of temperature on the performance of dye-sensitized solar cells based on a propyl-methyl-imidazolium iodide electrolyte”. University on Ljubljana,Slovenia. 2007. Available at: http://www.sciencedirect.com/science/article/pii/S0927024807000499

Cleveland, F. 2010. “Specification for PV & Storage Inverter Interactions using IEC 61850 Object Models and Capabilities”.

CNET 2009. LaMonica, M. CNET news. Picture of PV cleaned from snow. Available at: http://news.cnet.com/8301-11128_3-10156471-54.html

DOE 2010. US Department of Energy. “2008 Solar Technologies Market report”. 2010. Available at: http://www.nrel.gov/analysis/pubs_solar.html

EC 2008. Photovoltaic Geographical Information System (PVGIS). European commission. Available at: http://re.jrc.ec.europa.eu/pvgis/index.htm

Ecobusinesslinks 2011. PV-panel market price information.14.6.2011. Available at: http://www.ecobusinesslinks.com/solar_panels.htm

Ecofys 2011. Bömer, J., Burges, K., Zolotarev, P., Lehner, J., “Impact of Large-scale Distributed Generation on Network Stability During Over-Frequency Events & Development of Mitigation Measures”. Available at: http://en.solarwirtschaft.de/fileadmin/content_files/ecofys_50_2_hertz_short_en.pdf

Ecoseed 2011. Polintan, L.J. “M.I.T. researchers develop infrared-harnessing transparent solar cell.” Available at: http://www.ecoseed.org/technology-article-list/article/2-technology/9505-m-i-t-researchers-develop-infrared-harnessing-transparent-solar-cell

EFP 2003. Bosanac, M., Sørensen, B., Katic, I. “Photovoltaic/Thermal Solar Collectors and Their Potential in Denmark” EFP project 1713/00-0014. Final report. Copenhagen, 2003.

Elektroni 2011. Price for 120W solar panel. 14.6.2011. Available at: http://www.elektroni.fi/?product=15578

Energy masters 2011. Energy masters. Solar panel structure and current flow picture. Available at: http://www.energymasters.com/faq_questions.php#two

ES renewables 2010. Principle picture of solar heating system. 2010. Avaible at : http://esrenewables.tech.officelive.com/SolarWaterHeating.aspx

ESTTP 2010. Dalenbäck, J. Solar Heating plants presentation slide. [Cited 4.11.2011]. Available at : http://www.solarthermalworld.org/node/2880

Fortum solar 2011. CASE: Expedition to a solar economy. Available at: http://www.fortum.com/en/sustainability/sustainable-growth/cases/solar-economy/pages/default.aspx

Grama, S., Bradford, T. 2008. Thin-Film PV 2.0: Market Outlook Through 2012. Prometheus Institute and Greentech Media.

IPCC 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation, Intergovermental panel of climate change, 2011.

Junoka 2010. Picture of components of vacuum tube solar collector. Available at: http://www.junoka.fi/ene_aurinkolammitys%20lisatietoa%20tiedostot/Tyhjiokerainlisatietoa.htm

Kaygusuz, K., Ayhan, T. 1998. ”Experimental and theoretical investigation of combined solar heat pump system for residential heating”. Energy Conversion & Management, Vol. 40, 1999. Karadeniz Technical University, Turkey.

Kitunen, J. 2007. Aurinkosähkön soveltuvuus hajautettuun energian tuotantoon Suomessa. Master of Science thesis, Tampere University of Technology.

Kit Heung, L. 2003. ”Using Metal Hydride to Store Hydrogen”. Fuel Cells 2003 – Third Annual BCC Conference Stamford, CT, USA.

Kjellsson, E., Hellström, G., Perers, B. 2010. “Optimization of systems with the combination of ground-source heat pump and solar collectors in dwellings” Elsevier Energy, Vol. 35, Issue 6, pp. 2667–2673.

Knight, M., Sobhani, H., Nordlander, P. 2011. Photodetection with Active Optical Antennas. Science magazine, Vol. 332, 6th of May 2011.

Marinea 2011. Price for 140W solar panel. 14.6.2011. Available at: http://www.marinea.fi/shop/product_catalog.php?c=620&puoli=2

NASA 2005. Landis, G., Meritt,D., Raffaelle, R., Scheiman, D. “High-Temperature Solar Cell Development” NASA reports, 2005. Available at: http://gltrs.grc.nasa.gov/reports/2005/CP-2005-213431/27Landis.pdf

NREL Wikipedia 2010. NREL figure of efficiencies of solar panels. Available at: http://en.wikipedia.org/wiki/File:PVeff%28rev100921%29.jpg

NREL 2011. American Society for Testing and Materials (ASTM) Terrestrial Reference Spectra for Photovoltaic Performance Evaluation Datafile. Available at: http://rredc.nrel.gov/solar/spectra/am1.5/

PV-shop 2011. Price information of PV panels from German retailer. 22.6.2011. Available at: http://www.photovoltaik-shop.com/

Rimstar. Rimstar.org. Solar in winter issues. Available at: http://rimstar.org/renewnrg/solar_in_cold_climate_and_winter_snow.htm

Royne, A., Dey, C., Mills, D. 2004. ”Cooling of photovoltaic cells under concentrated illumination: a critical review. ”Solar Energy Materials and Solar Cells, Vol. 86, Issue 4, 1 April 2005, Pages 451–483. University of Sydney. 2004. Available at: http://www.sciencedirect.com/science/article/pii/S0927024804003071

SEGIS-ES 2008. Ton, D., Peek, G.H., Hanley, C., Boyes, J. “Solar Energy Grid Integration Systems – Energy Storage (SEGIS-ES)”. Program Concept Paper, May 2008.

Solar junction 2011. Brown, N. “Solar Junction breaks Concentrated Solar World Record with 43.5% Efficiency”, 2011. Available at: http://cleantechnica.com/2011/04/19/solar-junction-breaks-concentrated-solar-world-record-with-43-5-efficiency/

Solarshop 2011. Picture of two solar panels. Available at: http://www.solarpower.fi/products.php?p=ea9e83

Solartubs 2011. Layout of solar energy being used to preheat warm water. Available at: http://www.solartubs.com/Solar-water-heating/

Spectrolab 2011. King R. R. ”Raising the Efficiency Ceiling in Multijunction Solar Cells.” Available at: http://www.spectrolab.com/DataSheets/PV/pv_tech/msce.pdf

Statistics Finland 2010. Building information from 2010. Available at: http://www.stat.fi/til/rakke/2010/rakke_2010_2011-05-26_kat_002_en.html

Statistics Finland 2010. http://www.stat.fi/til/rakke/2010/rakke_2010_2011-05-26_kat_002_en.html

Strandby 2010. Strandby District Heating Station presentation. Available at: http://www.ener.gymap.dk/Profiles/SolarCAP/Cases/Strandby-District-Heating-Station

SunVoima 2010. Picture of roof installed solar collectors. Available at: http://www.aurinkokauppa.fi/WebRoot/Kaupat/Shops/Megantti/4897/FB85/3441/B6DC/AC3D/0A28/100B/D3EA/referenssi_1.jpg

Sørensen, B. 2005. "Hydrogen and fuel cells." Denmark. Elsevier Academic Press. 403 p.

Taguchi , M., Maruyama, E., Tanaka, M. 2007. "Temperature Dependence of Amorphous/Crystalline Silicon Heterojunction Solar Cells." Japanese journal of advanced physics, Vol. 47, No. 2, 2008, pp. 814–818.

Thermosun 2011. Price details for 135W panel. 14.6.2011. Available at: http://www.thermosun.fi/epages/Kaupat.sf/fi_FI/?ObjectPath=/Shops/Kuvaus/Products/4200/SubProducts/4200-0001

Vasilis, M. F., Hyung, C. K. (Kjell(Kje2007. "Greenhouse-gas emissions from solar electric- and nuclear power: A life-cycle study." Energy policy, Vol. 35, pp. 2549–2557.

Wikipedia 2011. A picture of PV panel current and voltage data. Available at: http://en.wikipedia.org/wiki/File: Solar-Cell-IV-curve-with-MPP.png

Appendix A: List of solar energy research institutions

The first list is from

http://energy.sourceguides.com/businesses/byP/solar/byB/research/research.shtl

National Renewable Energy Laboratory (NREL)
As the nation's leading center for renewable energy research, NREL is developing new energy technologies to benefit both the environment and the economy.

- **Business type:** government research laboratory
- **Product types:** renewable energy information.
- **Service types:** research
- **Address:** 1617 Cole Blvd., Golden, Colorado USA 80401
- **Telephone:** 303-275-3000
- **Web Site:** http://www.nrel.gov

US Renewable Energy Association

USREA is a volunteer renewable energy advocacy organization. We are made up of members just like you from across the USA. We rely on input, news and perspective from our members and partner companies to help spread the word about technologies that are revolutionary, and have the potential to change the way we power our future. We seek participation from schools, renewable companies, researchers and R. E. enthusiasts to assist with content and perspective, so we can share with others. We can only get better with your participation, so we look to our members to make this a great site. Do you belong?

- **Business type:** nonprofit organization, trade association
- **Product types:** photovoltaic systems, wind turbines (small), backup power systems, biomass energy systems, electric cars, alternative home and building construction materials hydro, biomass.
- **Service types:** research services
- **Address:** 6697 Lakeshore Road, Lexington, Michigan USA 48450
- **Telephone:** 810-359-2250
- **FAX:** 810-359-2250
- **Web Site:** http://www.usrea.org
- **E-mail:** Send Email to US Renewable Energy Association

New Energy and Industrial Technology Development Organization (NEDO)

NEDO was established in 1980, immediately after the second oil crisis, as a semi-governmental organization under the Ministry of International Trade and Industry in fields related to technological development in Japan. NEDO's activities include such fields as development and promotion of new energy and energy conservation technologies, research and development of industrial technologies, restructuring of Japan's domestic coal mining industry, production of industrial alcohol and restoring damaged coal mining area.

- **Business type:** nonprofit organization, research institution, government organization
- **Product types:** solar photovoltaic, solar thermal, wind energy and other new energy technologies.
- **Address:** Sunshine 60 Bldg. 3-1-1 Higashi Ikebukuro, Toshima-ku, Tokyo, Japan 170-6028
- **Telephone:** (03) 3987-9403
- **Web Site:** http://www.nedo.go.jp

Institute of Energy Conversion

A multidisciplinary laboratory devoted to research and development of thin-film photovoltaic cells.

- **Business type:** nonprofit organization, research organization
- **Product types:** thin-film solar photovoltaic cells (PV cells).
- **Service types:** research and development, consulting
- **Address:** University of Delaware, Newark, Delaware USA 19716
- **Telephone:** (302) 831-6200
- **FAX:** (302) 831-6226
- **Web Site:** http://www.udel.edu/iec/index.html
- **E-mail:** Send Email to Institute of Energy Conversion

Florida Solar Energy Center

- **Business type:** trade association, research institution
- **Product types:** energy efficient homes and buildings, solar water heating systems, photovoltaic systems, solar water pumping systems.
- **Service types:** consulting, project development services, education and training services, research services
- **Address:** 1679 Clearlake Road, Cocoa, Florida USA 32922
- **Telephone:** 321-638-1004
- **FAX:** 321-638-1010
- **Web Site:** http://www.fsec.ucf.edu

Centro de Investigacion en Energia

- **Business type:** Research Institution, Government Organization
- **Product types:** Photovoltaic systems designs for rural aplications, Solar water heating low temperature systems designs for domestic and industrial aplications, Solar drying systems for agriculture products, Water treatment with high temperature solar heating systems. Thin films solar control coatings .
- **Service types:** Material characterization: optical and electrical properties; X ray analysis; educational services, photovoltaic training courses, photovoltaic and thermal equipment development and evaluation, feasibility studies on photovoltaic and photothermal technologies.
- **Address:** Priv. Xochicalco s/n, Temixco, Morelos Mexico 62580
- **Telephone:** +52 (777) 325 0052 or +52(55) 5622 9725
- **FAX:** +52(777) 325 0018 or +52(55) 5622 9744
- **Web Site:** http://www.cie.unam.mx
- **E-mail:** Send Email to Centro de Investigacion en Energia

Netherlands Energy Research Foundation (ECN)

The Netherlands Energy Research Foundation (Energieonderzoek Centrum Nederland, ECN) is an independent Dutch organisation for long-term research and medium-term development in the field of energy, as well as the associated short-term services and transfer of knowledge. ECN focuses its activities on the needs and wishes of industry, energy sector and government in order to contribute, through target-oriented development and transfer of knowledge and technology, to innovative solutions for its target groups and customers. ECN works, with sustainability as a guideline, on the development of a reliable, environmentally sound and cost-effective energy economy and aims at internationally recognised expertise through selected spearheads.

- **Business type:** nonprofit organization, research institution
- **Product types:** solar energy, wind energy.
- **Service types:** research services
- **Address:** P.O. Box 1, 1755 ZG Petten, The Netherlands
- **Telephone:** +31 224 564949
- **FAX:** +31 224 564480
- **Web Site:** http://www.ecn.nl
- **E-mail:** Send Email to Netherlands Energy Research Foundation (ECN)

Centre for Energy Studies

- **Business type:** research institution
- **Product types:** Research on Renewable Energy Systems, Organizing Training programs and Seminars on Energy related issues, publications like Journals and Proceedings.

- **Service types:** research services
- **Address:** Ramna, Dhaka, Dhaka, Bangladesh 1000
- **Telephone:** 880 2 8614640-4
- **FAX:** 880 2 8613046
- **Web Site:** http://www.buet.edu
- **E-mail:** Send Email to Centre for Energy Studies

Institut für Thermodynamik und Wärmetechnik

- **Business type:** research institution
- **Product types:** solar thermal energy systems.
- **Service types:** research and development
- **Address:** Pfaffenwaldring 6 , Stuttgart, Germany D-70550
- **Telephone:** +49 711-685-3535
- **FAX:** +49 711-685-3503
- **Web Site:** http://www.itw.uni-stuttgart.de
- **E-mail:** Send Email to Institut für Thermodynamik und Wärmetechnik

Nimbkar Agricultural Research Institute (NARI)

- **Business type:** nonprofit organization, research institution
- **Product types:** electric bicycles, wood burning stoves and furnaces, solar water heating systems, energy efficient lighting, biomass energy systems, alternative fuel vehicles.
- **Service types:** research services
- **Address:** P.O.Box 44, Phaltan, Maharashtra India 415523
- **Telephone:** 91-2166-22396/20945
- **FAX:** 91-2166-21328
- **Web Site:** http://nariphaltan.virtualave.net

Renewable and Appropriate Energy Laboratory (RAEL)

The Renewable and Appropriate Energy Laboratory (RAEL) is a unique new research, development, project implementation, and community outreach facility based at the University of California, Berkeley in the Energy and Resouces Group and the Department of Nuclear Engineering. RAEL focuses on designing, testing, and disseminating renewable and appropriate energy systems. The laboratory's mission is to help these technologies realize their full potential to contribute to environmentally sustainable development in both industrialized and developing nations while also addressing the cultural context and range of potential social impacts of any new technology or resource management system.

- **Business type:** research institution
- **Product types:** solar and renewable energy research and development.
- **Service types:** education and training services

- **Address:** 4152 Etcheverry Hall, University of California, Berkeley, Berkeley, California USA 94720
- **Telephone:** 510-643-2243
- **FAX:** 510-643-6344
- **Web Site:** http://socrates.berkeley.edu/~rael/rael.html

Sandia National Laboratories Photovoltaic Program

- **Business type:** nonprofit organization, government organization, research organization
- **Product types:** photovoltaic cells (PV cells, solar cells), photovoltaic modules (PV modules, solar panels).
- **Service types:** research and development
- **Address:** USA
- **Web Site:** http://www.sandia.gov/pv

Schatz Energy Research Center (SERC)

The Schatz Energy Research Center has over sixteen years of experience working in the areas of renewable energy, energy efficiency and hydrogen energy systems. SERC s mission is to promote the use of clean and renewable energy. SERC works primarily on research and development, technology demonstration, project development, energy systems analysis, and education and training. In addition, SERC performs feasibility studies, resource assessments, and energy planning studies. Examples of past projects include the design and development of custom proton exchange membrane (PEM) fuel cells and fuel cell test stands, zero emission vehicles, and solar hydrogen power systems. As scientists and engineers, we are dedicated to our research. As teache...

- **Business type:** nonprofit organization, research institution
- **Product types:** fuel cell test stands, fuel cells, solar hydrogen power systems, renewable energy consulting services and feasibility studies.
- **Service types:** education, training and consulting services
- **Address:** Humboldt State University, Arcata, California USA 95521
- **Telephone:** 707-826-4345
- **FAX:** 707-826-4347
- **Web Site:** http://www.schatzlab.org
- **E-mail:** Send Email to Schatz Energy Research Center (SERC)

The Solar Foundation

The Solar Foundation is a 501(c)(3) nonprofit organization that focuses on national solar research and education that promotes the widespread adoption of solar energy, our cleanest, greatest and most available energy source. The Solar Foundation was founded in 1977 under the name Solar Energy Research and Education Foundation and is based in Washington,

DC. Our research and education efforts are on the front-line, driving the solar market and helping people recognize the value of solar as a clean energy source that promotes energy independence and security.

- **Business type:** nonprofit organization
- **Address:** 575 7th Street NW Suite 400, Washington, Washington DC USA 20004
- **Telephone:** 202-469-3750
- **FAX:** 202-682-0559
- **Web Site:** http://www.thesolarfoundation.org
- **E-mail:** Send Email to The Solar Foundation

Centre for Energy Studies

- **Product types:** photovoltaic systems, DC to AC power inverters, backup power systems, energy efficient lighting, meters and measuring equipment, uninterruptible power supplies UPS.
- **Service types:** consulting, design, education and training services, research services
- **Address:** Indian Institute of Technology, Delhi, New Delhi, New Delhi India 110016
- **Telephone:** 91-11-659 6417
- **FAX:** 91-11-686 2037

Earth Wind And Solar Energy, LLC.

- **Product types:** solar panel mounting systems roof mount, solar water heating systems, DC to AC power inverters, wind turbines (small) vertical axis, geothermal energy systems, solar lighting systems.
- **Service types:** design, installation, site survey and assessment services, contractor services, maintenance and repair services
- **Address:** 2350 W Grand Ave, Chicago, Illinois USA 60612
- **Telephone:** 312-243-9933

Ekomation Solar Energy Consultancy

- **Business type:** independent consultancy, research, business intelligence, service
- **Product types:** photovoltaic systems, solar water heating systems, photovoltaic modules, solar outdoor lighting systems, policy studies.
- **Service types:** consulting, project development services, research services, financial services
- **Address:** PO Box 29112, Rotterdam, Netherlands 3001 GC
- **Telephone:** +31-10-2807264
- **FAX:** +31-10-2807265

Fraunhofer Institute for Solar Energy Systems ISE

- **Business type:** research institution
- **Product types:** photovoltaic modules, photovoltaic systems, solar electric power systems.
- **Address:** Oltmannsstr. 5, Freiburg, Germany D-79100
- **Telephone:** +49 (0) 7 61 45 88-0
- **FAX:** +49 (0) 7 61 45 88-100

Global Market Consultants, Inc.

- **Product types:** photovoltaic cell manufacturing equipment, photovoltaic cells, photovoltaic modules, photovoltaic systems, energy efficient homes and buildings, solar water heating components, CSP.
- **Service types:** consulting
- **Address:** 25400 US 19 North, Suite 154, Clearwater, Florida USA 33763
- **Telephone:** 727-239-7609
- **FAX:** 727-216-3200

Institut für Solarenergieforschung GmbH

- **Business type:** research institution
- **Product types:** photovoltaic cells, solar thermal energy systems.
- **Service types:** research services
- **Address:** Am Ohrberg 1, D-31860 Emmerthal, Germany
- **Telephone:** ++49(0)5151-999-0
- **FAX:** ++49(0)5151-999-400

Institut für Solartechnik SPF (Solar Energy Lab)

- **Business type:** Research and Testing Laboratory
- **Product types:** Solar Thermal Energy Materials, Components, Collectors, and Systems. Software..
- **Service types:** Testing, Research and Development
- **Address:** Oberseestrasse 10, Rapperswil, Switzerland CH-8640
- **Telephone:** +41 (0) 55 222 48 21
- **FAX:** +41 (0) 55 222 48 44

Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H

- **Business type:** research institution
- **Product types:** solar thermal energy systems.
- **Service types:** research and development
- **Address:** Faradaygasse 3, Objekt 230, Wien, Austria A - 1030

- **Telephone:** (+43 1) 797 47-282
- **FAX:** (+43 1) 797 47-595

Rashron Energy and Auto Ltd

- **Business type:** manufacturer, exporter, research institution
- **Product types:** electric bicycles, solar cooking systems, wind turbines (large).
- **Address:** 603, GIDC, Makarpura, Vadodara, Guj India 390010
- **Telephone:** 0265 643224
- FAX: 0265 643778

Search results for "solar energy" in IEEE database

NREL, 493 results

NASA lewis research center Cleveland, 88 results

Fraunhofer-Inst. fur Solare Energiesysteme, Freiburg, 77results

Sandia National research labs Albuquerque New Mexico, 72 results

Jer propulsion lab, California institute of technology, 46 results

Institute of energy conversion, Delaware University, Newark, 60 results

RCA laboratories,Princeton, New Jersey, 42 results

IMEC,Leuven, 31 results

Toyota Technol. Inst., Nagoya, 27 results

ECN Solar Energy, Petten, Netherlands, 25 results

Tokyo Univ. of Agric. & Technol., Japan, 24 results

Spectrolab Inc., Sylmar, CA, USA, 20 results

Centre for Photovoltaic Devices & Syst., New South Wales Univ., Kensington, NSW, 19 results

Energy Conversion Devices Inc., Troy, MI, 17 results

Dept. of Phys., Konstanz Univ., Germany, 15 results

US Naval Res. Lab., Washington, DC, 14 results

Southern Methodist University, Dallas, Texas 75275, 11 results

Sch. of Electr. Eng. & Autom., Tianjin Univ., Tianjin, China, 11 results

Series title and number

VTT Technology 15

	# Arctic solar energy solutions
Author(s)	Riku Pasonen, Kari Mäki, Raili Alanen & Kari Sipilä
Abstract	Solar energy installations in Northern Europe mostly consist of small independent PV systems and solar heat collectors integrated to warm water supply of a household. Some larger solar heat plants are in use and have been planned in Northern Europe. Combined heat and power (CHP) solar energy systems are very rare because the concept is challenging but very interesting due to heating needs in the Northern countries. More research in this field is needed and especially in high temperature solar cells to increase possibilities for use of CHP in PV solar plants. Although solar irradiation is lower in Northern Europe, the difference to central Europe is not large as is commonly believed. The real reason for high PV capacity in Germany compared to e.g. Finland is the feed-in tariff system, not the actual difference in irradiation. Solar heat collectors together with regular heating systems can decrease heating costs in some cases. Prices of solar panels have decreased but PV panel prices in Finland do not appear to reflect global market prices. Photovoltaic solar energy production integration to energy system poses some challenges. One of the challenges is maximum power tracking of PV panels in power conversion devices to be able to operate at maximum available efficiency on different conditions. Grid protection reliability can suffer from distributed generation units and personal safety issues. Due the fact that solar production is concentrated to summer months and that production fluctuates also daily, there is a limit how much solar production can be connected to grid. One option could be to use energy storages to balance plant output but batteries are still too expensive for this. Heat storages are cheaper and they can be used in large solar thermal plants which generate electricity from solar heated steam turning turbines.
ISBN, ISSN	ISBN 978-951-38-7824-5 (soft back ed.) ISSN 2242-1211 (soft back ed.) ISBN 978-951-38-7825-2 (URL: http://www.vtt.fi/publications/index.jsp) ISSN 2242-122X (URL: http://www.vtt.fi/publications/index.jsp)
Date	March 2012
Language	English
Pages	79 p. + app. 8 p.
Name of the project	Arctic Solar Solutions
Commissioned by	VTT
Keywords	Solar cell, photovoltaic, electricity, energy storage, accumulator, solar radiation, arctic region
Publisher	VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111

Julkaisun sarja ja numero
VTT Technology 15

Nimeke	**Arktiset aurinkoenergiaratkaisut**
Tekijä(t)	Riku Pasonen, Kari Mäki, Raili Alanen & Kari Sipilä
Tiivistelmä	Pohjois-Euroopassa aurinkoenergiajärjestelmät ovat pääasiassa pieniä itsenäisiä aurinkosähkö- ja aurinkolämpöjärjestelmiä integroituna kotitalouksien sähkö- ja lämminvesijärjestelmiin. Muutama suurehko aurinkolämpöjärjestelmä on käytössä Pohjois-Euroopassa mm. Tanskassa. Aurinkosähkön ja -lämmön yhteistuotanto (CHP) on hyvin harvinaisia, sillä tekniikka on vielä kehitysvaiheessa, mutta mielenkiintoinen Pohjoismaissa tarvittavan sähkön ja lämmityksen takia. Aurinko energia sopii myös hyvin rakennusten jäähdytyksen tuotantoon. Aurinkoisella säällä juuri jäähdytyksen tuotanto ja kulutus ovat suurimmillaan. Alan tutkimusta tarvitaan lisää erityisesti korkean lämpötilan aurinkokennoissa, jotka mahdollistavat sähkön ja lämmön PV yhteistuotannon. Vaikka säteilyn määrä on alhaisempi Pohjois-Euroopassa, ero Keski-Eurooppaan ei ole suuri niin kuin yleisesti uskotaan. Meillä säteilymäärä kertyy vain lyhyemmässä ajassa kesällä. Todellinen syy korkeaan PV kapasiteettiin esim. Saksassa verrattuna Suomeen on syöttötariffijärjestelmä. Peruslämmitysjärjestelmään yhdistettynä aurinkoenergialla voidaan vähentää lämmityskustannuksia. Aurinkopaneelien maailmanmarkkinahinnat ovat laskeneet viime vuosina, mutta Suomessa PV paneelien hinnat eivät näytä seuraavan maailmanmarkkinahintakehitystä. Aurinkosähkötuotannon integrointi sähköenergiajärjestelmään on haasteellista. Eräs haaste on PV paneelien maksimitehon seuranta muunnoslaitteissa siten, että ne pystyvät toimimaan mahdollisimman tehokkaasti vaihtelevissa olosuhteissa. Verkkosuojauksen luotettavuus voi kärsiä hajautetussa tuotannossa ja henkilökohtaiseen turvallisuuteen liittyvissä kysymyksissä. Auringon tuotannon keskittymisestä kesäkuukausiin ja tuotannon päivittäisestä vaihtelusta johtuen on olemassa raja, kuinka paljon aurinkoenergiaan perustuvaa tuotantoa voidaan kytkeä verkkoon. Energian varastointi on yksi vaihtoehto tasapainottaa tuotantoa, mutta akut ovat edelleen liian kalliita tähän tarkoitukseen. Lämpövarastot ovat halvempia ja niitä voidaan käyttää suurissa aurinkolämpövoimalaitoksissa tuottamaan höyryä turpiineihin auringottomana ajankohtana.
ISBN, ISSN	ISBN 978-951-38-7824-5 ISSN 2242-1211 (nid.) ISBN 978-951-38-7825-2 (URL: http://www.vtt.fi/publications/index.jsp) ISSN 2242-122X (URL: http://www.vtt.fi/publications/index.jsp)
Julkaisuaika	Maaliskuu 2012
Kieli	English, Finnish abstr.
Sivumäärä	79 s. + liitt. 8 s.
Avainsanat	Solar cell, photovoltaic, electricity, energy storage, accumulator, solar radiation, arctic region
Julkaisija	VTT PL 1000, 02044 VTT, Puh. 020 722 111

VTT Technical Research Centre of Finland is a globally networked multitechnological contract research organization. VTT provides high-end technology solutions, research and innovation services. We enhance our customers' competitiveness, thereby creating prerequisites for society's sustainable development, employment, and wellbeing.

Turnover: EUR 300 million
Personnel: 3,200

VTT publications

VTT employees publish their research results in Finnish and foreign scientific journals, trade periodicals and publication series, in books, in conference papers, in patents and in VTT's own publication series. The VTT publication series are VTT Visions, VTT Science, VTT Technology and VTT Research Highlights. About 100 high-quality scientific and professional publications are released in these series each year. All the publications are released in electronic format and most of them also in print.

VTT Visions
This series contains future visions and foresights on technological, societal and business topics that VTT considers important. It is aimed primarily at decision-makers and experts in companies and in public administration.

VTT Science
This series showcases VTT's scientific expertise and features doctoral dissertations and other peer-reviewed publications. It is aimed primarily at researchers and the scientific community.

VTT Technology
This series features the outcomes of public research projects, technology and market reviews, literature reviews, manuals and papers from conferences organised by VTT. It is aimed at professionals, developers and practical users.

VTT Research Highlights
This series presents summaries of recent research results, solutions and impacts in selected VTT research areas. Its target group consists of customers, decision-makers and collaborators.

Arctic solar energy solutions

Solar energy installations in Northern Europe mostly consist of small independent PV systems and solar heat collectors integrated to warm water supply of household. Some larger solar heat plants are in use and planned in Northern Europe. Combined heat and power (CHP) solar energy systems are very rare because concept is challenging but very interesting due to heating needs in northern countries. More research in this field is needed and especially in high temperature solar cells to increase possibilities for use of CHP in PV solar plants.

Although solar irradiation is lower in Northern Europe, the difference to central Europe is not large as commonly believed. The real reason for high PV capacity in Germany compared to e.g. Finland is the feed-in tariff system, not the actual difference in irradiation. Due the fact that solar production is concentrated to summer months and that production fluctuates also daily, there is a limit how much solar production can be connected to grid. One option could be to use energy storages to balance plant output, but batteries are still too expensive for this.

ISBN 978-951-38-7824-5 (soft back ed.)
ISBN 978-951-38-7825-2 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 2242-1211 (soft back ed.)
ISSN 2242-122X (URL: http://www.vtt.fi/publications/index.jsp)