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Solar photovoltaic (PV) energy; latest developments in the building integrated and hybrid PV systems

A. Zahedi*

Solar Photovoltaic Energy Applications Research Group, Department of Electrical and Computer Systems Engineering, Monash University, Wellington Road, Clayton, Vic. 3168, Australia

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Abstract

Environmental concerns are growing and interest in environmental issues is increasing and the idea of generating electricity with less pollution is becoming more and more attractive. Unlike conventional generation systems, fuel of the solar photovoltaic energy is available at no cost. And solar photovoltaic energy systems generate electricity pollution-free and can easily be installed on the roof of residential as well as on the wall of commercial buildings as grid-connected PV application. In addition to grid-connected rooftop PV systems, solar photovoltaic energy offers a solution for supplying electricity to remote located communities and facilities, those not accessible by electricity companies.

The interest in solar photovoltaic energy is growing worldwide. Today, more than 3500 MW of photovoltaic systems have been installed all over the world. Since 1970, the PV price has continuously dropped [8]. This price drop has encouraged worldwide application of small-scale residential PV systems. These recent developments have led researchers concerned with the environment to undertake extensive research projects for harnessing renewable energy sources including solar energy. The usage of solar photovoltaic as a source of energy is considered more seriously making future of this technology looks promising.

The objective of this contribution is to present the latest developments in the area of solar photovoltaic energy systems. A further objective of this contribution is to discuss the long-term prospect of the solar photovoltaic energy as a sustainable energy supply.

Keywords: Solar PV energy systems; Grid-connected; Off-grid

* Tel.: +61 3 9905 5957; fax: +61 3 9905 3454.
E-mail address: ahmad.zahedi@eng.monash.edu.au.

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1. Introduction

According to the Earth Policy Institute (EPI), the global production of solar PV cells increased 32% in 2003, ahead of the most recent 5-year average of 27% a year. Production jumped to 742 MW, with cumulative world production at 3145 MW at the end of 2003, enough to meet the electricity needs of one million homes. According to EPI, this extraordinary growth is driven to some degree by improvements in materials and technology, but primarily by market introduction programs and government incentives [7].

Since 2000, Sharp has sustained annual growth of 63% and holds 27% of the world market, followed by Kyocera, Shell Solar, BP Solar, and RWE Schott Solar. Japanese production accounts for 49% of the world total.

The global solar industry is worth US$7 billion a year and is expected to continue growing as solar cell manufacturing costs decrease. Off-grid applications were the initial market for PV cells but the grid-connected sector has grown significantly since 1996 and, in 2003 grid-connected applications accounted for 77% of the total market around the world.

2. Main applications for photovoltaics power systems

There are four major applications for PV power systems:

2.1. Off-grid domestic photovoltaic systems

These systems provide electricity to remote located households and villages that are not connected to the national electricity grid. Theses PV systems usually provide electricity for lighting, refrigeration and other low power loads. Thousands of these type of PV systems have been installed worldwide and they are often the most appropriate technology to meet the energy demands of off-grid communities. Off-grid domestic systems are typically around 2 kW in size and generally offer an economic alternative to extending the electricity distribution grid at distances of more than 1 or 2 km from existing power lines [1,3].

2.2. Off-grid non-domestic photovoltaic systems

These systems are the most appropriate applications, where small amount of electricity has a high value, so making PV commercially cost competitive with other small generating sources. These systems were the first commercial application for terrestrial PV systems. They provide power at a low maintenance for a wide range of applications, such as telecommunication, water pumping, vaccine refrigeration and navigational aids.

2.3. Grid-connected distributed photovoltaic systems

These photovoltaic systems supply power to a building or other load that is also connected to the utility grid. These systems are usually integrated into the built environment and supply electricity to residential houses, commercial and industrial

buildings. There is no need for battery storage units as these systems are connected directly to national electricity grid, thus the costs of these systems are lower compared to an off-grid installation. Typical systems are between 1 and 100 kW in size. Electricity is fed back into the utility grid when the on-site generation exceeds the demand of the load. Grid-connected PV systems nicely match the residential load pattern during hot summer days [2,11].

2.4. Grid-connected centralized photovoltaic systems

These systems are installed for two main purposes: as an alternative to conventional centralized power generation, or for strengthening the utility distribution system.

3. Photovoltaic cell and module production

The PV cell and module manufacturers continue to grow strongly. Since 2000, Sharp has sustained annual growth of 63% and holds 27% of the world market, followed by Kyocera, Shell Solar, BP Solar, and RWE Schott Solar. Japanese production accounts for 49% of the world total and has benefited from a variety of government incentive programs, including the 1994 solar roof program with a goal of 70,000 systems, which had reached 144,000 systems by 2002 despite a reduction in the subsidy from 50 to 10% of installation cost. This has been shown in Fig. 1 [12].

Main applications for solar PV in developed countries are grid-connected rooftop PV systems for residential or commercial buildings. The typical size of these systems is from 1 kW to many kW depending on the applications.

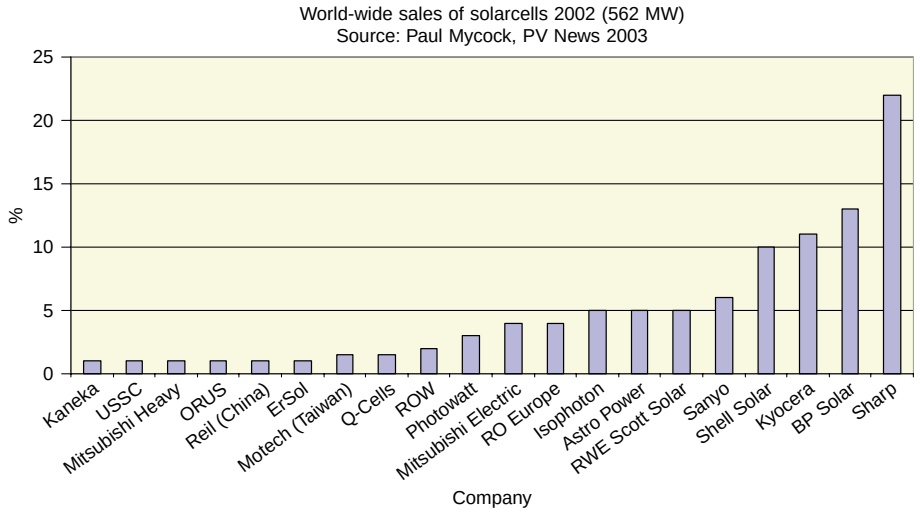

Fig. 1.

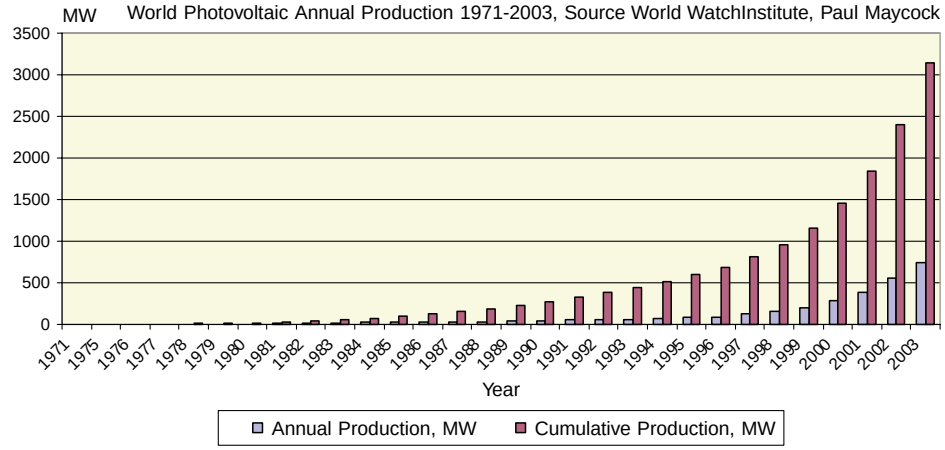

Fig. 2.

Fig. 2 shows the world annual and cumulative production of photovoltaic panels, while Fig. 3 shows the annual growth of PV production in the past 23 years [4,12].

Main applications for solar PV in developing countries are small solar home systems, (SHS), for households (typically 200–500 W), village power stations (typically 500–2500 W), and power for health centers, schools, water pumping and telecommunications systems. For the remote or rural areas of developing countries, which account for much of the market in these countries, PV is often a cost effective solution to energy service provision [9,10].

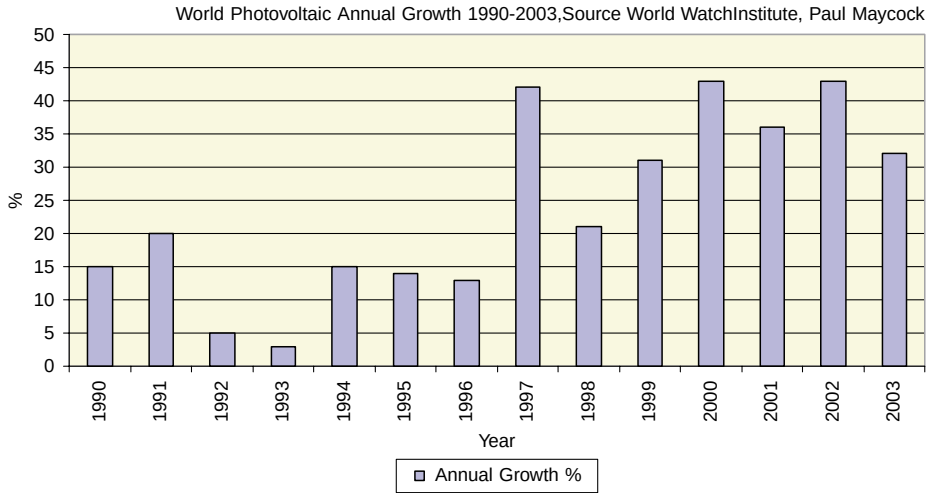

Fig. 3.

Table 1
Installed price of PV energy systems in US $/W

Off-grid		Grid-connected	
<1 kW	>1 kW	<10 kW	>10 kW
09.00–25.00	08.00–24.00	05.00–12.00	04.00–10.00

4. System prices

Prices for entire PV systems vary widely and depend on a variety of factors including system size, location, customer type, grid connection, technical specification and, as a consequence of creative marketing, the extent to which end-user prices reflect the real costs of all the components.

System prices for off-grid applications in each country tend to be higher by about a factor of two than those for grid-connected applications as the latter do not require storage batteries and associated equipment.

In 2003, system prices in the off-grid sector up to 1 kW varied from about 8–25 USD per watt depending on the country and project. A system price of about 10–12 USD per watt appears to be common. Off-grid systems greater than 1 kW tend to show similar variation and prices.

The installed price of grid-connected systems also depends on countries. The lowest reported prices were close to 4 USD per watt. Variation of installed system prices in USD per watt in 2003 for off-grid and grid-connected PV systems has been shown in Table 1.

Table 2

Japan	1992	New Sunshine Program: established to introduce renewable energy throughout the country. Targets were set and a net metering law enacted
Japan	1994	70,000 Roofs Program: initially, 50% of PV installation costs were subsidized and the annual budget (for R&D and market incentives) was $18.3 million. In 2003, the subsidy was reduced to 15% and the budget allocation increased to $186 million
United States	1997	Million Solar Roofs Initiative: national program designed to facilitate the installation of solar energy systems on 1 million US buildings by 2010
Germany	1998	100,000 Roofs Program: provided 10-year loans with reduced interest rates to buyers of PV systems. It ended early, in 2003, when all targets were met
Germany	1999	Renewable Energy Sources Act (Feed-In Tariff): customer applications receive 56 per kWh for solar-generated electricity sold back to the grid
Italy	2001	10,000 Roofs Program: regions offer different investment subsidies to promote building-integrated photovoltaic applications
Japan	2003	Renewable Power Portfolio Standard: requires that renewable energy be provided at a constant percentage of the electric power supply. This legislation aims for renewable energy to be 3.2% of the total by 2010
China	2004	Allocation of $1.21 billion to adopt solar and wind energy for power generation in remote areas of West China
Switzerland	2003	Switzerland has the highest solar energy use per capita in the world: 1.82 W per capita

Table 3

Year	USA (MW)	Europe (MW)	Japan (MW)	Worldwide (MW)
2000	140	150	250	1000
2010	3000	3000	5000	14,000
2020	15,000	15,000	30,000	70,000
2030	25,000	30,000	72,000	140,000

5. Government incentives for solar energy

There was a significant increase in the annual installed PV generation capacity in most developed countries. This was driven largely by key Government support programs. Examples of these government incentives in some selected countries have been shown in Table 2 [5].

6. Expected future direction of solar energy technology

Solar photovoltaic technology could harness the sun's energy to provide large-scale, domestically secure, and environmentally friendly electricity.

All buildings will be built to combine energy-efficient design and construction practices and renewable energy technologies for a net-zero energy building. In fact the building will conserve enough and produce its own energy supply to create a new generation of cost-effective buildings that have zero net annual need for non-renewable energy.

Photovoltaics research and development will continue intense interest in new materials, cell designs, and novel approaches to solar material and product development. It is a future

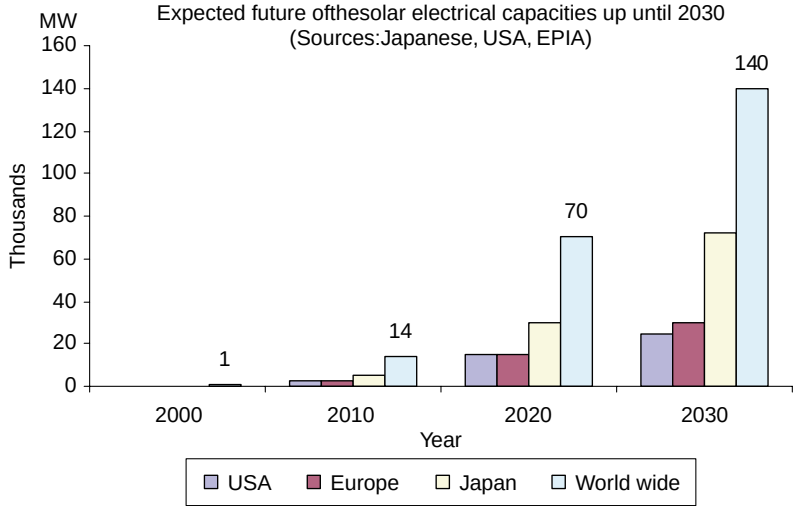

Fig. 4. Expected future of solar PV electricity, USA, Europe, Japan and world.

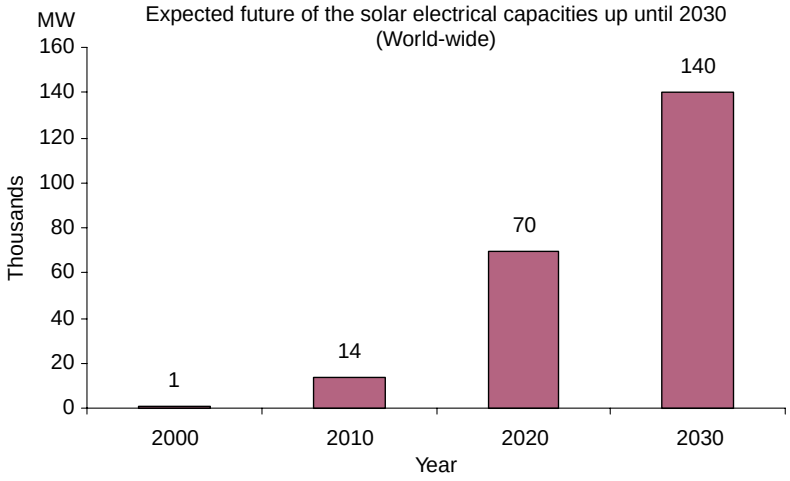

Fig. 5. Expected future of solar PV electricity, worldwide.

where the clothes you wear and your mode of transportation can produce power that is clean and safe.

The price of photovoltaic power will be competitive with traditional sources of electricity within 10 years. Solar electricity will be used to electrolyze water, producing hydrogen for fuel cells for transportation and buildings.

Table 3 [5] shows expected development and installation of solar photovoltaic electricity in the USA, Europe, Japan as well as worldwide up until 2030, while Figs. 4–7 show these data graphically [6,7].

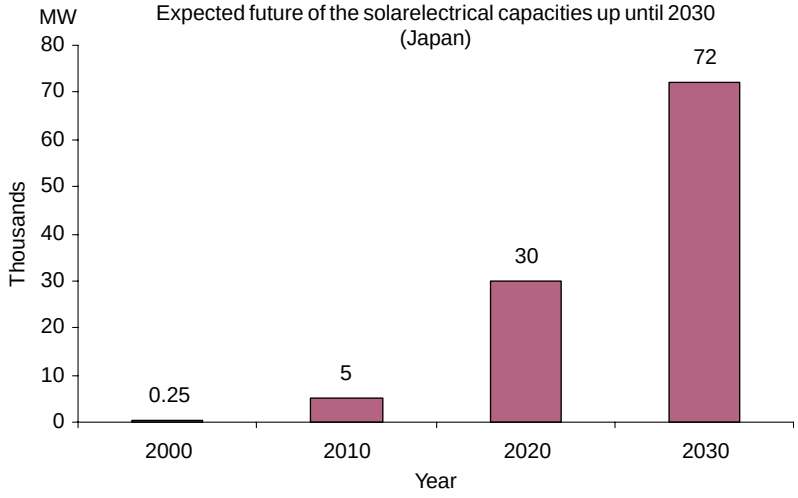

Fig. 6. Expected future of solar PV electricity, Japan.

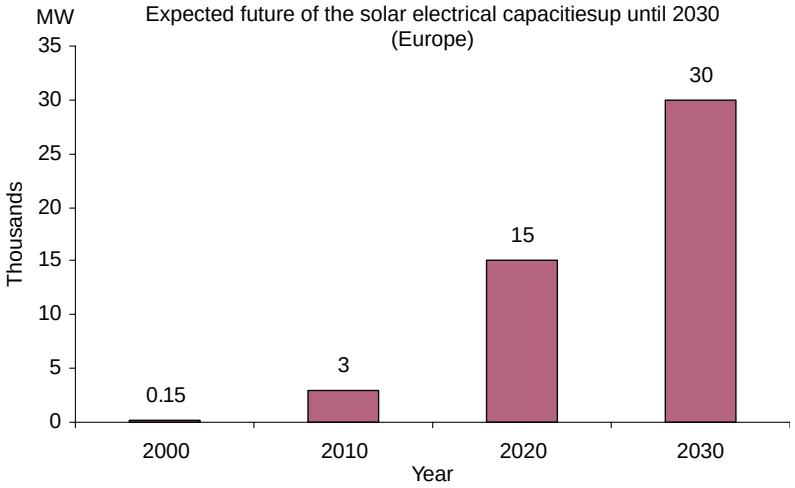

Fig. 7. Expected future of solar PV electricity, Europe

7. Author's remarks on potential of solar power in Iran

The potential of solar power in Iran is comparable in scale to all country's available power resources. A desert area 10 km by 10 km could provide 15,000 MW of power, while the electricity needs of the entire IRAN could theoretically be met by a photovoltaic array within an area 15 km on a side.

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