Solar energy power systems as renewable energy technique of the future

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This paper presents technology concentrating solar power (CSP) generating electricity by using the heat from solar thermal collectors to heat a fluid which produces steam that is used to power the generator. Main concentrating solar power technologies are described in this article on brief: parabolic troughs, linear Fresnel, power towers, and solar dish. Producing electricity with central solar emits no pollution, produces no greenhouse gases, and no uses finite fossil fuel resources. The environmental benefits of centrals solar are great.

1. Introduction

The dramatic increase in global energy demand and the imminent fossil fuel shortage are a compelling motivation for the improvement of solar energy utilization for distributed electricity generation and for the heat energy transmission. Energy is essential to economic and social development and improved quality of life in all countries. Electricity supply infrastructures in many developing countries are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth [1]. It is well known that global demand for energy is rising rapidly. The Department of Energy of the United States of America estimates that by 2015, global energy consumption will increase by over 34 %, with the strongest growth expected in the developing economies of China, India, and other Asian nations [2]. At the same time, the American economy and many other economies around the world are expected to decrease their reliance on fossil fuels, which produce CO_2, a known greenhouse gas. The need to control atmospheric emissions of greenhouse and other gases and substances is due to layer ozone depletion, which protects the earth from solar radiation. Ultraviolet (UV) solar radiation affects many natural processes and any increase in the radiation intensity is of concern, due to potential harmful effects on the biosphere [3]. Each square meter of concentrator surface, for example, is enough to avoid 200 to 300 kilograms (kg) of CO_2 each year, depending on its configuration. Typical power plants are made up of hundreds of concentrators arranged in arrays.

In such context, the exploitation of solar energy, as it is a renewable source, is very promising if systems are designed to ensure continuous energy supply even in the absence of daylight.

The quantity of solar energy available at a specific site is a function of climatic factors and the relative motion of the sun with respect to the earth. Because of changes in the Earth's declination, elevation, zenith, hourly and azimuth angles, as well as seasonal changes, sunrise, and sunset times, the intercepted insolation greatly varies with time.

The inclinations of the intercepting surface and view factors also have a significant impact on the amount of recovered energy. Thus, the centrals solar with tracking systems are important in maximizing the recovered energy over a long period of time.

Solar energy can be converted to electricity in two ways: *photovoltaic (PV) or "solar cells"* change sunlight directly into electricity and *Concentrating Solar Power Plants (CSP)* generate electricity by using the heat from solar thermal collectors to heat a fluid which produces steam that is used to power the generator. Both types of solar power plants use solar concentrators to improve the efficiency of solar energy transformation. There are main types of concentrator: parabolic trough, Fresnel collector, solar dish and solar tower as in the figure 1. Parabolic trough give temperatures of 400 °C, solar tower 1000 °C and solar dish 750 °C. The higher temperature allows us to obtain higher efficiency of the solar power plant. The parabolic trough system was the first CSP technology, thus it is the most developed and most commonly replicated system.
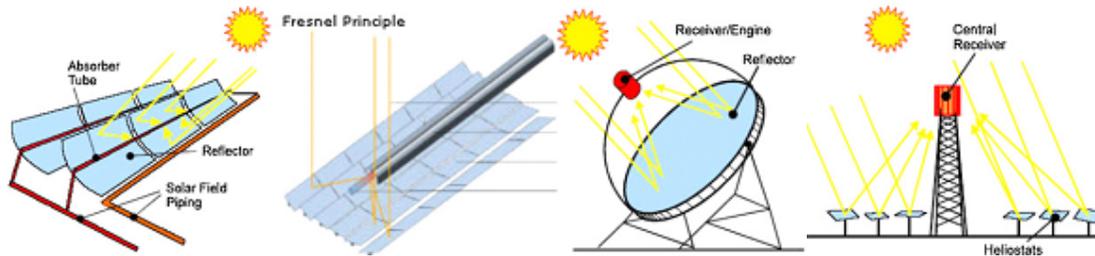
Fig. 1. Solar thermal technologies for the production of power (from left to right: parabolic trough, Fresnel collector, parabolic dish, solar tower) Source: SolarPACES.

2. Classification of concentrating solar power

Solar power is the generation of electricity from sunlight. This can be direct as with photovoltaics (PV), or indirect as with concentrating solar power (CSP), where the sun's energy is focused to boil water which is then used to provide power. Essentially, CSP plants include four main components: the concentrator, receiver, transport-storage, and power conversion.

2.1 Photovoltaic

Photovoltaic (PV) cells use semiconductors to produce electricity. Photovoltaic cell is an electronic device similar with a diode, absorbing solar radiation, which excites the electrons inside the cell. As primary material for manufacturing a semiconductor is used, often crystalline or polycrystalline silicon on the surface which is formed by various technological methods. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module', as in the Fig. 2.

Fig. 2. Photovoltaic [Sevilla].

2.2 Parabolic trough

Parabolic trough – systems use parabolic trough shaped mirror reflectors to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line. Individual parabolic trough collector modules are attached together to form a "collector" that can be from 100 to 150 m long. Collectors are configured together to

form a collector row. Parabolic trough plants are made up of many parallel collector rows covering large rectangular areas of land. The troughs are usually designed to track the Sun along one axis, predominantly north–south. A thermal transfer fluid, such as synthetic thermal oil, is circulated in these tubes. The fluid is heated to approximately 400 °C by the sun's concentrated rays and then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator (e.g. Rankine-cycle), which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle (figure 3). A parabolic trough has efficiency up to 21 %.
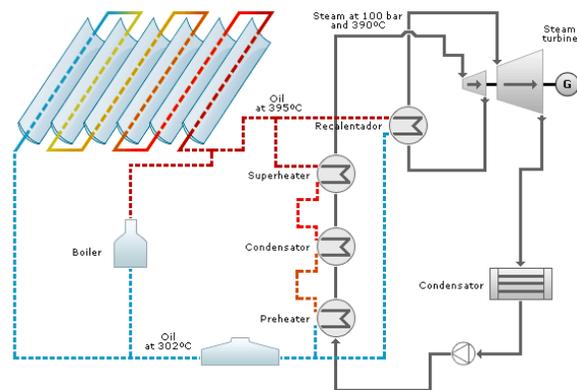

Fig. 3. Schematic of power parabolic trough system - 1st generation [5].

2.3 Integrated Solar Combined Cycle System (ISCCS)

The ISCCS has generated much interest because it offers an innovative way to reduce cost and improve the overall solar-to-electric efficiency. A combined cycle plant uses a gas combustion turbine as the first stage in electricity generation. The hot flue gases from the turbine pass through a heat exchanger (Heat Recovery Steam Generator) to generate steam. The fuel (preferably natural gas) is burned generally on a combustion chamber of a gas turbine. The steam drives a steam turbine as the second stage in the electricity production process. Combined cycle systems have heat-to-electricity efficiencies of approximately 55%.
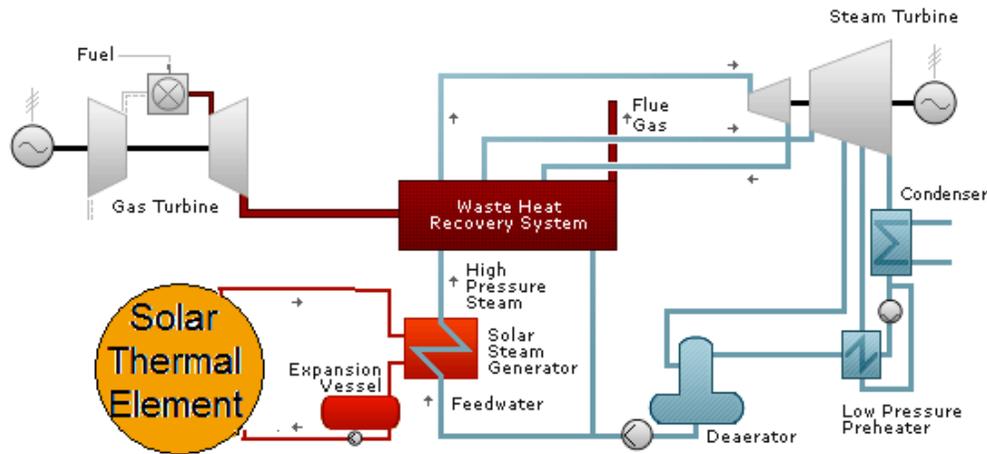
Fig. 4. CSP power generation in Integrated Solar Combined Cycle System [4].

ISCCS offers two main advantages over other power plants. First, the peak capacity of the power can be increased at a lower capital cost than other power plants because the main incremental cost (other than for the solar field) is for a larger steam turbine. Second, the integration of a solar system with a combined cycle boosts power often when it is needed most. Conventional combined cycle systems suffer a reduction in plant output when the outdoor temperature is high. The lower density of the air reduces the mass flow through the gas turbine and therefore reduces its output. Generally, the solar system has its peak output in early afternoon when the outdoor temperature is highest.

2.4 Parabolic dish

A parabolic dish – shaped reflector concentrates sunlight on to a receiver located at the focal point of the dish. The concentrated beam radiation is absorbed into a receiver to heat a fluid or gas (air) to approximately 750 °C. This fluid or gas is then used to generate electricity in a small piston or Stirling engine or a micro turbine, attached to the receiver. The troughs are usually designed to track the Sun along one axis, predominantly north–south.

The main challenge facing distributed-dish systems is developing a power-conversion unit, which would have low capital and maintenance costs, long life, high conversion efficiency, and the ability to operate automatically. Several different engines, such as gas turbines, reciprocating steam engines, and organic Rankine engines, have been explored, but in recent years, most attention has been focused on Stirling-cycle engines. These are externally heated piston engines in which heat is continuously added to a gas (normally hydrogen or helium at high pressure) that is contained in a closed system. The high solar concentration and operating temperatures of dish systems has enabled them to achieve conversion efficiencies of 30%.

2.5 Fresnel collector

An array of nearly - flat reflectors concentrates solar radiation onto elevated inverted linear receivers. Water flows through the receivers and is converted into steam. This system is line-concentrating, similar to a parabolic trough, with the advantages of low costs for structural support and reflectors, fixed fluid joints, a receiver separated from the reflector system, and long focal lengths that allow the use of flat mirrors. The technology is seen as a potentially lower-cost alternative to trough technology for the production of solar process heat.

2.6 Central receiver or solar tower

A circular array of heliostats (large mirrors with sun-tracking motion), with a surface area of 1291.67 ft^2 each (120 m^2), concentrates sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy, which is used to generate superheated steam for the turbine (figure 4). To date, the heat transfer media demonstrated include water/steam, molten salts and air. If pressurized gas or air is used at very high temperatures of about 1,000°C or more as the heat transfer medium, it can even be used to directly replace natural gas in a gas turbine, making use of the excellent cycle (25 – 30 % and more) of modern gas and steam combined cycles.

The central receiver absorber can heat the working fluid or an intermediate fluid to a temperature as high as 600 to 1,000 °C which can be used to drive a Rankine cycle or Brayton cycle.

An alternative to steam systems is the molten salt tower. This approach offers the potential for very low-cost storage that permits dispatch of solar electricity to meet peak demand periods and a high capacity factor (~70%).
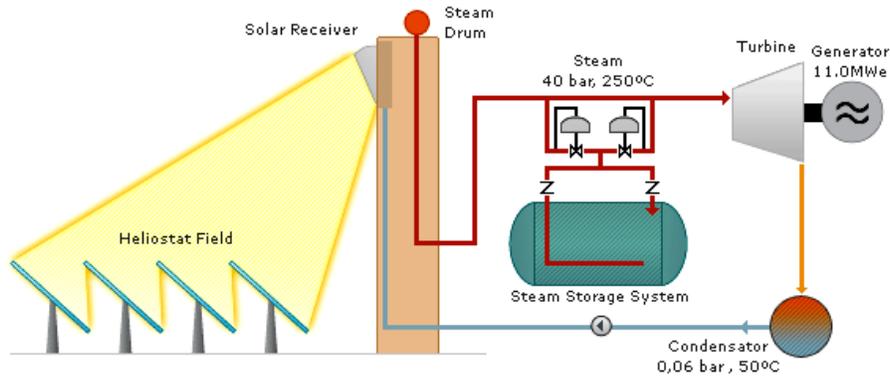
Fig. 4. Schematic of power tower system - 1ˢᵗ generation [5].

3. Results and discussion

The sun is by far the most significant source of renewable energy. The total irradiance on a horizontal surface on Earth is also called global irradiance. It is the sum of the direct irradiance and the diffuse irradiance on the horizontal surface.

Figure 5 gives an overview of monthly average global irradiation values for some locations around the world. It clearly demonstrates that there are significant variations between different locations. There are significant differences between these locations. Average annual solar global irradiation for Timisoara is 1.41 (kWh/m^2) [15]; for Berlin is 2.80 (kWh/m^2) [14]; for Roma is 4.18 (kWh/m^2) [14] and for Cairo is 5.32 (kWh/m^2) [14]. Cairo as an example for a location with relatively high annual irradiation.
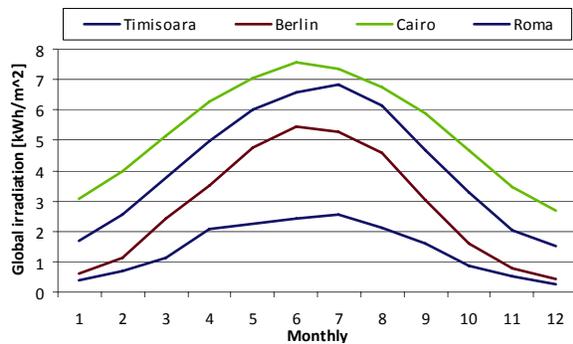

Fig. 5. Monthly Average Values in kWh/m^2 day of the Daily Global Irradiation.

Illumination of the receiver is defined as an incident light flux per unit surface of the receptor, in this case, sensor of the Extech Datalogging Light Meter. Illumination is measured in Lux (lx).

$$E = \frac{d\phi_{inc}}{dS} \qquad (1)$$

In Fig. 6 an example of a time variation of the illumination, for the whole day 09.04.2010 of experimental program, is presented. The measurement interval extends from 09.17 to 19.12. The maximum value of illumination is 15,248; the range using of between 0 to 20,000. During day the average value of the illumination is 1,479.36 Lx. This is
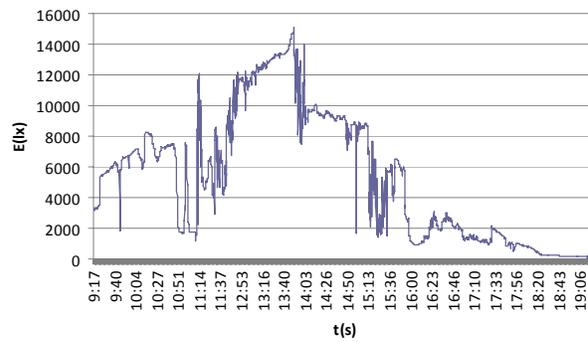

Fig. 6. Illumination E (lx) in the day 09.04.2010, Timisoara.

In Fig. 7 is presented the illumination variation during the day 11.04.2010, only the diffuse radiation due to covered sky conditions. Measurement interval extended from 08.11 to 16.00. The maximum value of illumination is 1,997, the range using of between 0 to 2,000. During day the average value of the illumination is 918 Lx.
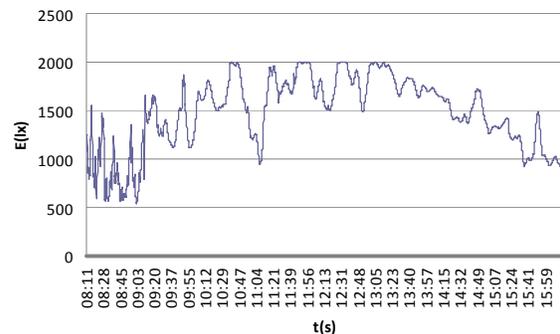

Fig. 7. Illuminarea E (lx) in the day 11.04.2010, Timisoara.

Table 1 shows typical values for technologies of the cell photovoltaic efficiency in the laboratory (2004) and production.

The efficiency is defined as the ratio of maximum power of the cell and solar radiation measured on this surface:

$$\eta = \frac{P_{max}}{\phi_{inc}} = V_{OC} I_{SC} \frac{FF}{\phi_{inc}} \qquad (2)$$

Where is: FF - fill factor, V_{oc} - open circuit voltage, I_{sc} - short circuit current [A],
Φ_{inc} - incident flux.

In the case of ideal solar cell, the fill-factor is a function of open circuit parameters and can be calculated as follows (Stone):

$$FF \approx \frac{v_{OC} - \ln(v_{OC} + 0.722)}{v_{OC} + 1} \qquad (3)$$

Where is: v_{oc} - voltage calculated with equation:

$$v_{OC} = V_{OC} \frac{q}{m \cdot k \cdot T} \qquad (4)$$

Where is: k - Boltzmann constant = 1.38×10^{-23} [J/K], T - temperature [K],
q - charge of electron = 1.6×10^{-19}, m - diode ideality factor.

Table 1 shows a sample of measured data and calculation of the efficiency. The significance of measures are the following: η – efficiency of the cell photovoltaic, V_{OC} - open circuit voltage [V], I_{sc} - short circuit current [A] and FF- fill factor.

Table 1. Laboratory and production cell photovoltaic efficiency.

Type	Laboratory				Production
	η [%]	V_{OC} [V]	I_{SC} [mA· cm^{-2}]	FF [%]	η [%]
mono-Si	24.7	0.706	42.2	82.8	15-18
multi-Si	19.8	0.654	38.1	79.5	13-16
a-Si (single layer)	12.7	0.887	19.4	74.1	7.0
a-Si / µc-Si	14.5	-	-	-	12.5
CdTe	16.5	0.845	25.9	75.5	7.0
CIS	18.4	0.669	35.7	77.0	6.5-10
GaAs	25.1	1.022	28.2	87.1	-
GaInP / GaInAs /Ge	31.3	2.392	16.0	81.9	27-28

For all practical purposes, Solar Energy is inexhaustible. The yearly irradiation on total earth amounts to more than 1 billion terrawatthours. That is more than 60.000 times the global power demand.

Spain is the epicenter of CSP development with 22 projects for 1,037 MW under construction, all of which are projected to come online by the end of 2010. The current Spanish Royal Decree, which calls for 500 MW of solar CSP by 2010, has been largely responsible for the dramatic increase in CSP development activity in Spain since 2008.

United States are known 11 concentrating solar power generating units operating in at the end of 2008, 9 of these are in California, 1 in Arizona, and 1 in Nevada.

While parabolic trough represents more than 96 % of all CSP projects currently under construction in Spain, and U.S. represents only 40 % of all CSP projects. The Table 2 shows installed capacity [MW] and electricity [GWH] for concentrating solar power [4].

Table 2. Installed capacity and produced electricity by technology type (approximate numbers).

Technology type	Installed capacity 2009 [MW]	Electricity produced up to 2009 [GWh]	Approximate capacity, under construction and proposed (MW)
Parabolic trough	500	>16,000	>10,000
Solar tower	40	80	3,000
Fresnel collector	5	8	500
Solar dish	0.5	3	1,000

Fig. 8 shows the status of international developments and the evolution of the energy costs of parabolic trough and central receiver power plant projects.
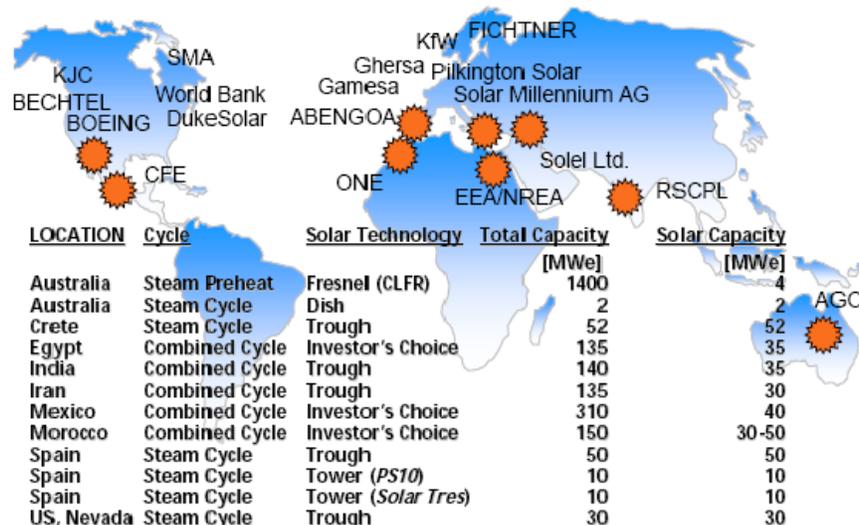
Fig. 8. The status of international developments of solar thermal power plant projects (Source: DLR-Almería)

The difference between main types of commercial CSP technologies is parabolic troughs and Fresnel collector systems which concentrates the sunlight in linear fashion, central receivers and parabolic dishes which are focusing the sunlight in the point.

4. Conclusions

Solar energy technologies are one of the renewable with the most potential for growth in the near future. The technology has been proven to be feasible and reliable, which is often untrue about many other renewable sources.

Solar energy technologies' promising future can be forecast through the incredible technical advances and research that is currently being done. The solar energy technology is one of the best solutions for future energy production. It is clean, storable and will eventually become less expensive than fossil fuel.

Acknowledgment

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