enerMENA CSP Teaching Materials

Chapter 1
Introduction

Authors
Dr.-Ing. Thomas Fend¹,
Dr.-Ing. Louy Qoaider²,

¹ German Aerospace Center (DLR) -Solar Research, Linder Höhe 51147 Cologne, Germany
² German Aerospace Center (DLR), Solar Research Plataforma Solar de Almería (DLR-PSA), Ctra. de Senés s/n, 04200 Tabernas, Spain
1. Introduction
The term CSP (Concentrated Solar Power) comprises technologies used to generate electricity by the concentration of the direct solar beam and the use of a conventional thermal process. The technology was introduced first in large scale in the early 1980’s as a result of efforts initiated to response to the oil crisis in 1970’s, long before global warming has become an issue. It has been considered as a technology for large scale electricity production to partly replace fossil power stations. Since CSP uses direct solar radiation it is a technology to be used in regions with excellent solar resources, such as in regions of the so called world’s Sun Belt. CSP is a special renewable technology capable to also provide base-load electricity. This is a unique feature, which gains importance in the current change of the energy market, which will increasingly be dominated by other renewable sources such as wind energy and photovoltaics, whose output is more weather dependent.

Many aspects, which can act as a motivation to deal with CSP-Technology, are valid for any other solar technology as well. Driven by the question „what’s beyond the fossil age?“ people thought about solar resources in general and came to the conclusion that there is enough solar radiation to supply the world’s energy demand. Figure 1 demonstrates this impressively and shows the orders of magnitude we are talking about. Solar radiation available on Earth is approximately 10000 times the current annual demand of primary energy of mankind. However, this is only a theoretical statement; if you take Germany’s daily per capita consumption of approximately 150 kWh primary energy, as an example, you may shortly calculate, that 400 m² of photovoltaic panels would be necessary to cover the demand for each person. This sounds impressing and shows that it is self evident, that people are thinking about the question of what’s beyond the fossil age with a rather global approach.

![Figure 1: Proportions of World’s energy resources and demand](image)

Besides the limited fossil resources and the intention to avoid an energetic „bottle neck“ that means a sudden deficiency of energy coming along with high energy prices causing possible
economic crisis a new motivation arose in the 1990’s: global warming caused by the emission of greenhouse gases. Along with the continuously published reports from the Intergovernmental Panel of Climate Change (IPCC)\(^3\) it became clear, that anthropogenic global warming is a fact with severe consequences for mankind such as the rise of sea level, the change of the pattern of precipitation, the desertification, the retreat of permafrost, glaciers and sea ice and many more. This is certainly one of the largest global problems existing and it led to numerous international conferences on strategies to solve or at least confine this problem.

One important global approach to overcome the energy and climate change problem is the DESERTEC concept, which was developed by a network of politicians, scientists and economists from around the Mediterranean.\(^4\) The concept is illustrated in Figure 2 and it foresees a large scale generation of regenerative electricity in the Middle East and North African (MENA) deserts to supply EU-MENA region with electricity. The figure also demonstrates roughly the area required to cover several energy demand sizes in the year 2005.

\[\text{Figure 2: Desertec concept: using deserts to supply Europe’s and MENA countries with solar electricity}\]

---


1.1 The enerMENA Teaching Materials

The enerMENA Teaching Materials cover a wide spectrum of topics related directly to CSP technologies. They range from theoretical and scientific topics to practical exercises, which are close to the application in the everyday-work of engineers and technicians employed in CSP-companies.

CSP is a technology, which comprises a broad field of academic disciplines ranging from scientific fundamentals such as optics and thermodynamics to engineering fields like thermo-fluids or turbo-machinery. Even knowledge on economy is needed since implementing a CSP plant means feasibility studies, site selection, financing etc. The enerMENA Teaching Materials treat all those topics (see Figure 3). However, every current CSP-Technology is coupled to any kind of heat engine and almost every CSP technology works with some kind of working fluid. Therefore, a roll-back of the basics in thermo-fluid engineering and conventional power plants is provided in Chapters 3 and 4.

Figure 3 CSP topics spectrum in the enerMENA Teaching Materials

The limitation of fossil fuels and the increasing fear of the rising energy prices motivated many countries to support research and development as well as economic activities on renewable energies, especially on CSP. So, even before becoming economic competitive, the first commercial European CSP plant was successfully erected in Spain with the support of the governmental feed-in-tariff programme to pay for the generated electricity. The PS10 solar tower near Seville in Southern Spain started operation in 2006 [5]. The „Solar Tower Technology“ is treated in Chapter 8 of this course. More large scale plants were erected in Spain few years after that, such as the three ANDASOL-plants, each of which has a capacity of 50 MW electrical power.

---

The three Andasol power plants were built with the so called parabolic trough technology (Figure 4), the one, which has also been used to build the first CSP-plants at all; the SEGS-plants in California in the 1980’s. These have a total amount of electrical power output of more than 300 MW and they are in operation until today. Trough Technology is the matter of Chapter 5. The two remaining main CSP technologies, Fresnel-collectors and dishes (Figure 4) are treated in Chapters 6 and 7 respectively.

Figure 4: CSP-technologies: dishes, towers, parabolic trough- and Fresnel-collectors (from left to right).

The selection of suitable sites to build new CSP plants is an important aspect while studying the CSP technologies and their implementation. Therefore this is addressed in Chapter 14 of this study course. Also essential are the topics of market introduction and cost reduction of CSP technologies. These are covered in Chapter 15. Furthermore, the operation and maintenance aspects are presented in Chapter 12 and the quality control and optimisation of the power plants’ components are tackled in Chapters 11.

To transmit the electricity generated in the deserts to population centers, a new sufficient grid connection is necessary, probably via High Voltage Direct Current technology. Large investments are necessary to realise this requirement including the R&D works. Chapter 13 (Electric Power Transmission) is dedicated to this topic. Additionally, social and strategic aspects are discussed in Chapter 16.

The CSP-plants are able to generate electricity for base load exactly like thermal power plants despite the fact that, the solar radiation is not available 24h/day. However, it is necessary to increase the size of the collector field so that it delivers additional heat to be stored for later generation after sunset. The increase of the solar field area is called “solar multiple”, which should be in best cases at least 3 to enable a „solar only“ non-stop operation of the turbine. In times when the solar direct radiation decreases below a certain limit, the thermal engine must be fed by the power of a thermal storage. Therefore, most of CSP plants are equipped with a thermal...
storage system. In this context, a variety of storage technologies exists and there are enormous development efforts of the storage technologies at the moment. This topic is addressed in Chapter 9 (Thermal Energy Storage).

Although CSP technology is mainly considered as an electricity generating technology, there are „secondary applications” such as solar thermal cooling, desalination of water or direct thermal generation of hydrogen. These are seen as by-products to electricity generation process by utilising directly the solar heat generated from CSP collector technology or the process waste heat. The (secondary applications) are presented in Chapter 10.

Finally, it was essential to address the unique natural resource of power; solar radiation, in the enerMENA teaching materials (Chapter 2). The chapter includes a discussion on “why it makes sense to concentrate the solar radiation”. This could shortly be answered as follows: A CSP power plant involves a thermal power engine to convert heat into power. A thermal power engine usually works more effective at higher temperatures. These high temperatures can only be reached by concentrating the solar beam. A theoretical efficiency optimum occurs for every CSP-system depending on its concentration ration. Figure 5 shows that the optimum theoretical efficiency of a solar system in relation to its concentration factor. For that reason, a lot of R&D activities are performed on developing reflecting materials and on components with high concentration factors. More on solar radiation, its origin, techniques to estimate solar resources at a certain site, calculation of the solar beam direction and concentration can be found in Chapter 2 of this course.

![Figure 5: Theoretical efficiency of a CSP-system as a function of temperature for different concentration factors](image-url)