View of 3 CSP Power stations near Seville

Solar Thermal Power

The Science and Technology of Solar Thermal Power in Africa

By Daniel Schäfer

Energy is the most important of resources and the foundation of all human endeavours. The ubiquity and extensive availability of affordable energy provides the basis for the wealth of the technologically developed world. The energy problem that the world is facing at the beginning of the 21st century is a complex Issue comprised of three facets: availability, economic efficiency and sustainability. How we respond to this problem will determine the shape of tomorrow. Paradoxically, that energy source with the greatest sustainable potential is also the least used: our sun. Solar thermal power stations could provide a possible renewable and environmentally sustainable energy source of tomorrow. These scientific, technical and instrumental fundamentals will be addressed in this article.

We will demonstrate how large-scale solar thermal power facilities in North Africa could cost-effectively provide Western Europe with a substantial part of its energy requirement. Moreover, there is the possibility of making solar energy available for Africa. This could happen in either the form of electricity or as the power source for energy intensive desalination plants , eventually providing a fresh water supply. Especially the latter aspect could be a model for other arid regions and contribute to meet the increasing demand for drinking water in times of shrinking resources.

The Potential of Solar Power

Sunlight is an easily available and sustainable energy source. The projected 'operating time' of the sun is measured in hundreds of millions of years and will be available to mankind for an indefinite time into the future. The amount of solar radiation per year on earth is equal to about 1.6 billion terawatt hours (TWh) and is about 10,000 times the annual global energy requirement. In other words, the world's energy demand could be met in one day if the Sun's energy was used completely. This is why solar power has by far the greatest potential of all of the renewable energy sources including: wind, water, biomass, and geothermal power among others. This is even more important with a view to future increases in energy consumption.

Applications and Limitations

Currently, there are two methods of obtaining utilizable energy from solar radiation: photovoltaic and solar thermal. We've gotten used to the blue shimmering panels that cover roofs. These photovoltaic facilities directly convert solar radiation into electricity. In contrast, the solar thermal method uses sunlight to convert solar radiation into heat. This heat then runs a thermal power facility, usually a steam system, and finally electricity is generated.

The annual amount of energy from solar radiation of 1.6 billion terawatt hours that was described above is not distributed evenly over the earth's surface. There is less solar radiation in the higher latitudes because of the tilt of the earth's axis as well as seasonal variations. Climate factors also play a role. For example, cloudier regions are exposed to less solar radiation. All of these factors make some regions of the earth more suitable for the massive generation of energy from solar radiation than others.

While it is possible to run photovoltaic facilities in northern regions, like Germany, this is not the case for solar thermal power stations. These facilities are limited to the sun-belt region if they are to run economically – that is to say, between 35 degrees north and south of the equator. However, the available landmass within this belt is enormous. The Sahara desert alone has a surface area of 9 million km2, of which about 18,000 km2 would be sufficient to cover the entire electricity requirements of Europe. 65,000 km2 could easily produce all the energy mankind currently uses.

One critical factor still needs to be discussed when exploring the utilization of solar energy. Solar radiation is only available for a limited amount of time during the day. Regardless of whether it's photovoltaic or solar thermal facilities that are used to generate electricity, the fact that at night there simply is no sunlight available for the production of energy must be accounted for. However, every technologically developed economy depends on the continuous availability of power that has no bottlenecks during the day or certain times of year. The technical term for this Is ‚Base load power'.

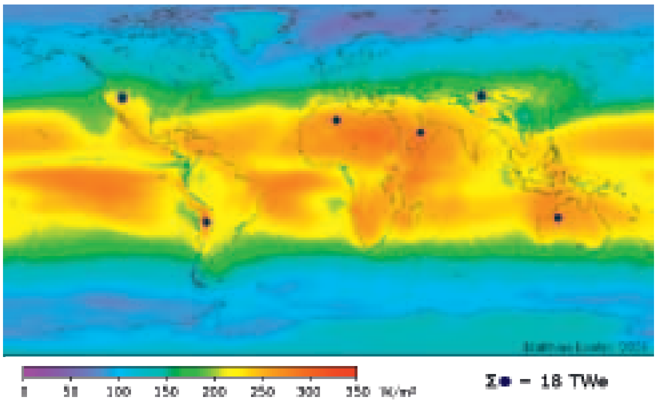
The Solar Thermal method: Power Station Engineering in Detail

Solar thermal power stations convert solar energy into heat, and then have steam run a turbine with a connected electricity generator. In the last decades different designs for solar thermal power stations were suggested and some were built in test facilities. Two principle designs seem to be particularly promising to run commercial mega power stations: parabolic power stations and solar power towers.

In solar trough power stations, parabolic mirrors (See image 2) focus the sunlight onto a pipe filled with a heat transfer medium, e.g. thermo-oil. Such solar troughs can be hundreds of metres long, are oriented along the north-south-axis, and follow the position of the sun. Many parallel lines of these solar troughs can be connected into power station blocks, producing (theoretically) several hundred mega watts of electricity. By comparison, the most powerful German brown-coal plant, the Niederaußem power station has a gross output of 3,864 megawatts; the most powerful nuclear power station – Brokdorf- has a gross output of 1,480 megawatts.

The particular shape of the parabolic mirrors limits the concentration of the sunlight. The working temperature reached in this way lies between 300-500 °C. Manufacturing flaws in the mirrors are hard to avoid entirely in economical mass-production which further reduces the focussing ability of the solar trough. Finally, the pipe networks, through which the heat absorbers run, affect the efficiency of the facility. The efficiency of this power station design is about 20 percent, that is to say 1/5 of the harvested solar radiation can be converted into electricity.

Foto: Mlino76



Globally available solar energy

The PS10 test facility in Seville, in southern Spain with an electrical capacity of 11 megawatts, demonstrates the possibilities of solar thermal tower power.

Solar tower power stations consist of concentrating mirrors, or heliostats, that follow the position of the sun precisely. These heliostats then focus the sunlight onto the tip of a tower, where the heat is collected and Injected Into a heat-absorbing medium, like air or water. The ability of the solar power towers to concentrate heat is much greater than with parabolic trough designs, and temperatures between 600-1,000 °C can be achieved. This is about equal to operating temperatures in conventional power stations like coal, natural gas, and nuclear power with a steam circulation. These high temperatures even make it possible to turn water into steam at the tip of the tower and to run a turbine directly instead of having to run over a medium and to create steam in a secondary circuit. The ability to highly concentrate the light means a very efficient conversion of solar energy into heat with an efficiency of 70 percent and more. Generally, the degree of efficiency of the complete solar power tower stations is about 25-40 percent. Large power stations consist of several thousand heliostats with surfaces of several dozen square metres each and a tower of 100-200 m in height could principally generate many hundred megawatts of electrical energy from sunlight.

At present, globally there are only a few test facilities of this design-type. The largest of these facilities, the PS10 in southern Spain near Seville, consists of 624 heliostats with a surface area of 120 m2 each and a tower of 115 m in height with a total capacity of 11 megawatts (see above). By 2013 several solar thermal power demonstration stations will be built in this region with a total capacity of about 300 Megawatts. in the Mojave Desert, California, several different power station types have already been built in pilot facilities and are operational by now. Together, they have a capacity of 350 mega-watts that they feed into the electrical grid.

Hybrid Power Stations and Energy Storage

Solar energy is available as a massive source of energy for the next millions of years and is also a source for low emission electricity. However, it does have one major deficit in contrast to conventional energy sources: It is only available during daytime. Base load capable power stations have to be able to provide sufficient amounts of electricity 24 hours a day to feed into the electrical grid. During the day, most consumption stems from private households and office buildings. Large technical facilities and industrial plants usually run at night, when the electrical requirements of private homes is lower and electricity is less expensive. In addition, the lighting of cities and streets by night also requires electricity.

The electricity generated by the small photovoltaic facilities, for example on the roofs of family homes, is stored economically feasibly in batteries. This is sufficient for minimal use at night and for use on cloudy days. This principle however does not apply to the large-scale supply of a country with solar electricity. Neither Is there a technology available today that Is powerful enough to store up sufficient amounts of electricity nor will this change In the foreseeable future. There are, however, in principle two methods for making electricity from solar thermal power stations available at night: heat storage, and supplemental fossil fuel use.

As discussed above, solar thermal power stations create heat in order to power a steam cycle with a turbine and a generator. Nothing precludes power station providers from using conventional energy sources, like natural gas, during periods without sunlight to generate heat. Commercial natural gas power stations have high capacities with moderate C02 emissions, and so economically reasonable electricity could also be provided at night. This division of labour between solar and conventional technologies has the drawback, though, that it rests on a non-renewable resource: natural gas. However, this may well be important in the transition period to a sustainable and environmentally friendly energy economy. These so-called ‚hybrid power stations‘ are conventional power stations that have the solar thermal component added on in order to save


High voltage direct current (HVDC) cables in Sweden

on fossil fuels. The big advantage of this type of power station is that in addition to saving fossil fuels it has a higher energy efficiency than conventional power stations.

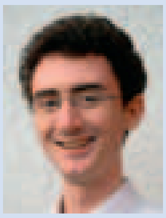
Heat storage facilities are, on the other hand, efficient methods to store heat created during the day for use at night. In this way, electricity can be produced from solar energy around the clock. Molten salt storage is a good possibility as it possesses very good thermal qualities, is inexpensive as well as available in large quantities. To avoid misunderstandings, with current technologies heat is much easier to store than electricity. Lead accumulators store electricity at costs of around 140 Euros and more per kWh. In contrast, the costs for heat storage facilities are between 10 – 30 Euros per kWh and are therefore significantly less expensive. Additionally, lead batteries can only hold 25-30 Wh per kg, so that gigantic storage facilities would be required if one wanted to store the quantities of electricity that correspond to several hours of typical energy output of a power station.

In southern Spain (37° north), ten hours of sunlight in the summer, and six hours in the winter are available to create electricity. In order to create electricity for use during the day but also to charge the heat storage for use at night requires an expansion of the collector field of the solar thermal power station. Typically, it would be increased by a factor of 2-4 in comparison to facilities that only produce energy during the day. Please note, that both basic considerations and experimental results from pilot facilities indicate that the efficiency of solar thermal power stations actually increases by about 20-30 percent when using heat storage. In this way it is possible to make solar thermal power stations suitable for operation as base load power stations.

Location – North Africa

The basic idea underlying this article is to create a future sustainable energy economy. This concept sees a great number of base loadable solar thermal power stations being built in southern Europe and northern Africa. The energy generated there would be transmitted to Europe using high-voltage direct current (HVDC) cables, a technology which will have a critical role to play. Especially the North African coastal areas like Algeria, Libya, and Egypt have large areas with a high degree of solar radiation, and in this respect would be ideal for the operation of solar thermal power plants. These otherwise uncultivated areas could be put to good use by being the site for the large-scale construction of power stations. Naturally, not every square kilometre of desert would be suitable for the construction of power stations. Various criteria like subsurface stability and other environmental factors like sandstorms etc. would have to be put Into consideration. Even so, the amount of useable land in this area of the world is more than sufficient.

The main building materials for solar thermal facilities are steel, concrete



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and glass for the structure of the power station as well as the heat transporting medium (air, thermal oil etc.), cooling fluid (water) to create steam, and a heat storage medium (molten salt). For each particular country in the North African desert region there are naturally interesting opportunities. The investment costs for the power stations, which are to generate electricity for Europe, lie in the area of billions of dollars. Also, the value of technology transfer should not be underestimated, as well as the creation of jobs in the region.

From a technical point of view, the central question regarding solar thermal power in North Africa is: How does the generated electricity get to the consumers in Europe? High voltage direct currents (HVDC) offer one possible solution.

It is for technical reasons that in transferring energy over longer distances, like several hundred to a few thousand kilometres, conventional alternating current cable systems suffer losses that are larger than those from the transfer of direct currents. The reason for this lies in the electromagnetic radiation (electro smog) and the di-electric charge reversal of the insulation materials. However, alternating currents can be conveniently produced by use of transformers and substations. Direct currents In contracst are technically more complicated and require the use of rectifiers and invertors.

However, for long distances it is worth the effort to convert the alternating current into direct current with high voltage (typically 100,000 – 1 million volts) for the transport. Typical projected losses for HVDC cables are somewhere around 3 percent per 1,000 km. Note that An alternating current cable at 50 Hz does not offer any useful electricity transfer for the same distance.

The HVDC has already been put Into operation successfully in commercial applications when Scandinavian hydropower stations were connected to the European and Baltic grid. A further example is the HVDC that runs across the English Channel and connects Great Britain's electrical grid with that of continental Europe. In 2010, an almost 2,100 kilometre long HVDC cable with a transfer capacity of 6,400 megawatts will be finished in China. This will connect the industrial centres of the Chinese east coast (Shanghai) with the hydropower stations in the interior of the country. India, South Africa, and Brazil have realized similar projects, so that worldwide almost 300 gigawatts of electricity are transported over long distances through HVDC and are hooked up to electrical networks. All this shows that the technology to transfer large amounts of energy over great distances is possible and commercially viable.

The connection of the North African solar thermal power stations with Europe could take three routes: over the strait of Gibraltar, Sicily or Sardinia. One energy scenario (Europe 20XX) sees the laying out of over 140 pairs of cables with a transfer capacity of 5 gigawatts each, and a length of about 3,000 kilometres. In this way, it would be possible to feed 700 gigawatts of generated solar electricity from North Africa into the European network.

Conclusion

The current energy economy is built on non-renewable resources, which will need to be replaced in the middle to long term. Energy from the sun's radiation promises an environmentally friendly, and inexhaustible service capacity. However this will require significant technical, economic, and political efforts. One of the most promising concepts is the construction of solar thermal power stations in the sunbelt of southern Europe and northern Africa. This energy can be transferred to Europe using High Voltage Direct Current and in this way supply Europe with electricity. •