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SOLAR UPDRAFT TOWERS

INFORMATION

ABSTRACT

The generation of largescale solar thermal electricity is technically feasible and will soon become economically competitive, if more efforts to introduce it are made. In this paper the state of the art of central largescale solar energy technology, especially solar updraft towers will be presented an will emphasize the role of the structural engineer in this important field.

KEY WORDS

- *solar energy*
- *high towers*
- *solar collector*

INTRODUCTION

Current energy provision systems based on exhaustible fuels such as coal, hydrocarbons and uranium are damaging the environment and are non-sustainable. Increasing prices due to limited resources and rising demand pose serious problems even for rich countries.
Powerty, the population explosion and migration are, amongst other reasons, also a consequence of insufficient energy supply and high energy costs. According to the International Energy Agency, about 1.6 billion people have no access to electrical energy, and about 2.4 billion have to rely on biomass for cooking and heating. These numbers are increasing. All people want to and should be able to use electricity in the future. Hence, the demand for electricity will dramatically increase, especially in developing and emerging nations. It would be very shortsighted to rely on coal and oil or even nuclear power. A clean inexhaustible source of energy is needed, i.e., the Sun.
Solar energy can be used in various indirect (biomass, hydro power, wind) and direct forms (solar thermal power, photovoltaic systems).
Sensible technology for the widespread use of renewable energy must be simple and reliable and accessible to technologically lessdeveloped countries that are sunny and often have limited raw material resources. It should not need cooling water, and it should be based on environmentally sound production from renewable or recyclable materials.
Solar updraft towers meet these conditions. Economic appraisals based on experience and knowledge gathered so far have shown that largescale solar updraft towers (> 100 MW) are capable of generating electricity at a cost comparable to that of conventional power plants. This is reason enough to further develop this form of solar energy utilization to encompass large, economically viable units. In a future energy economy, solar updraft towers could thus help assure the economic and environmentally benign provision of electricity in sunny regions.
The solar updraft tower's three essential elements - solar air collector, chimney/tower, and wind turbines -have been familiar for centuries.

FUNCTIONAL PRINCIPLE

The principle of the solar updraft tower is as follows: Air is heated by solar radiation under a low circular transparent or translucent roof open at the periphery; the roof and the natural ground below it form a solar air collector. In the middle of the roof is a vertical

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tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air, it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Continuous 24 hour-operation can be achieved by placing tight water-filled tubes or bags under the roof. The water heats up during the day-time and releases its heat at night. These tubes are filled only once; no further water is needed. Thus solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower and into electrical energy by conventional generators.

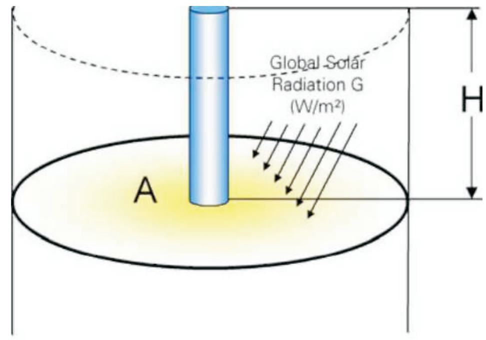
Collector

Hot air for the solar updraft tower is produced by the greenhouse effect in a simple air collector consisting of a glass or plastic glazing stretched horizontally several meters above the ground. The height of the glazing increases adjacent to the tower base, so that the air is diverted to vertical movement with minimal friction loss. This glazing admits the solar radiation component and retains long-wave re-radiation from the heated ground. Thus the ground under the roof heats up and transfers its heat to the air flowing radially above it from the outside to the tower.

Storage

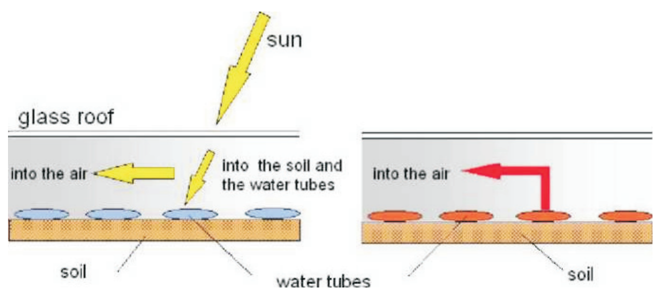
If additional thermal storage capacity is desired, waterfilled black tubes are laid down side by side on the radiationabsorbing soil under the collector. The tubes are filled with water once and remain closed thereafter, so that no evaporation can take place.

At night, when the air in the collector starts to cool down, the water inside the tubes releases the heat that it stored during the day. Heat storage with water works more efficiently than with soil alone, since even at low water velocities - from the natural convection in



$$P_{el} \sim A \times H$$

the tubes - the heat transfer between the water tubes and water is much higher than that between the ground surface and the soil layers underneath and since the heat capacity of water is about five times higher than that of soil.



Day Night

Tower Tube

The tower itself is the plant's actual thermal engine. It is a pressure tube with low friction loss (like a hydropower station pressure tube or pen stock) because of its favorable surface-volume ratio. The updraft velocity of the air is approximately proportional to the rise in air temperature (ΔT) in the collector and to the tower's height. In a multi-megawatt solar updraft tower the collector raises the air temperature by about 30 to 35 K. This produces an updraft velocity in the tower of (only) about 15m/s at nominal electric output, as most of the available pressure potential is used by the turbine(s) and therefore does not accelerate the air. It is thus possible to enter into an operating solar updraft tower plant for maintenance without danger from high air velocities.

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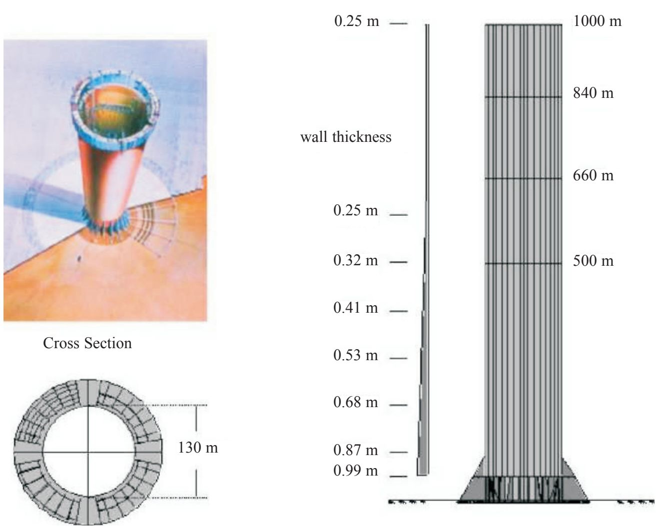
Layout of a Tower



Turbines

By using turbines, mechanical output in the form of rotational energy can be derived from the air current in the tower. Turbines in a solar updraft tower do not work with staged velocity like free-running wind energy converters, but as shrouded pressure-staged wind turbo generators, in which, similarly to a hydroelectric power station, static pressure is converted to rotational energy using cased turbines. Air speed before and after the turbine is about the same. The output achieved is proportional to the product of the volume flow per time unit and the pressure differential over the turbine. With a view to maximum energy yield, the aim of the turbine control system is to maximize this product under all operating conditions.
To this end, the blade pitch is adjusted during operation to regulate the power output according to the changing airspeed and airflow. If the flat sides of the blades are perpendicular to the airflow, the turbine does not turn. If the blades are parallel to the air flow and allow the air to flow through undisturbed, there is no pressure drop at the turbine, and no electricity is generated. Between these two extremes there is an optimum blade setting: the output is maximized if the pressure drop at the turbine is about 80% of the total pressure differential available. The optimum fraction depends on the plant's characteristics such as friction pressure losses.

PROTOTYPE

Detailed preliminary theoretical research and a wide range of wind tunnel experiments led to the establishment of an experimental plant with a peak output of 50 kW on a site made available by the Spanish utility Union Electrica Fenosa in Manzanares, which is about 150 km south of Madrid, in 1981/82, with funds provided by the German Ministry of Research and Technology.
The aim of this research project was to verify, through field measurements, the performance projected from calculations based on theory and to examine the influence of individual components on the plant's output and efficiency under realistic engineering and meteorological conditions.
These results show that the system and its components are dependable and that the plant as a whole is capable of highly reliable operation. Thermodynamic inertia is a characteristic feature of the system; continuous operation throughout the day is possible; and for large systems, even abrupt fluctuations in energy supply are effectively cushioned.

GENERAL SYSTEM CHARACTERISTICS

Apart from working on a very simple principle, solar updraft towers have a number of special features:

1. Unlike conventional power stations (and also some other solar-thermal power station types), solar updraft towers do not need cooling water. This is a key advantage in the many sunny countries that already have major problems with their water supply.
2. The collector can use all types of solar radiation, both direct and diffuse. This is crucial for tropical countries where the sky is frequently overcast.
3. Due to the soil under the collector working as a natural heat storage system, solar updraft towers can operate 24 h a day on pure solar energy and at reduced output during the night time. If desired, additional water tubes or bags placed under the collector

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roof absorb part of the radiated energy during the day and release it into the collector at night. Thus solar updraft towers can operate as base load power plants. As the plant's prime mover is the air temperature difference (causing an air density difference) between the air in the tower and ambient air, lower ambient temperatures at night help to keep the output at an almost constant level even when the temperature of the natural and additional thermal storage also decreases without sunshine, as the temperature *difference* remains practically the same.

4. Solar updraft towers are particularly reliable and not liable to break down, in comparison with other power plants. Turbines and generators - subject to a steady flow of air - are the plant's only moving parts. This simple and robust structure guarantees operation that needs little maintenance and of course no combustible fuel.
5. The building materials needed for solar updraft towers, mainly concrete and glass, are available everywhere in sufficient quantities. In fact, with the energy taken from the solar updraft tower itself and the stone and sand available in the desert, they can be reproduced on site. Energy payback time is two to three years.
6. Solar updraft towers can be built now, even in less industrially developed countries. The industry already available in most countries is entirely adequate for solar updraft tower requirements. No investment in high-tech manufacturing plants is needed.
7. Even in poor countries it is possible to build a large plant without high foreign currency expenditures by using the local resources and workforce; this creates large numbers of jobs while significantly reducing the required capital investment and thus the cost of generating electricity.

CONCLUSION

A solar updraft tower generates electricity using direct and diffuse solar radiation. It is based on a simple principle; its physics are well understood. As thermodynamic efficiency increases with the tower's height, solar updraft towers must be large to generate electricity at a competitive cost. Large power plants mean high investment costs, due to a large extent to the many construction workers required. This in turn means the creation of many jobs,which added value in the country itself. Solar updraft towers reduce the environmentally disastrous utilization of dwindling fossil fuels, while removing the need for costly imports of coal, oil and gas, which is especially beneficial for developing countries to release the means for their development The construction of solar updraft towers is not associated with resource consumption; the resources are merely bound for a certain time. As solar updraft towers mainly consist of concrete and glass, which is sand plus (self-generated) energy, they can reproduce themselves in the deserts - a truly sustainable source of energy.