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Large Scale Hybrid Solar-Hydrogen Electric Power Plants for Pakistan

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ABSTRACT

Pakistan has large-scale year-round cloud free, 'high sun' areas, through which the perennial Indus River flows – bringing voluminous water from the ice-capped mountains in the north. In this geography, pollution free, large-scale Solar-Hydrogen hybrid electric power plants, of the 'Solar-Tower' type, can be established on the sunny plains at a safe distance from the river. In this paper, the basic technology to extract round-the-clock electric power, the location of such power plants and basic feasibility is discussed. Solar thermal system, inducing high speed 'up-draft' wind, being the main turbine-rotating electricity generating configuration, hydrogen is proposed to be used as a back-up clean fuel. During solar active periods, along with direct generation of electricity, hydrogen could be produced by photoelectrolysis of the river water. During solar-wind inactive periods, electricity would be generated through hydrogen-based systems. Some modifications, to increase efficiency and usability of available options are also discussed.

Keywords: Renewable energy, solar-tower, thermal wind, hydrogen, photoelectrolysis.

1. INTRODUCTION

Pakistan, an oil importing country, lies in the dry temperate zone with its vast cloud-free areas drenched in high-level solar energy. However, perennial rivers, such as the Indus flow from the ice-capped northern mountains of the country to the vast 'high-sun' plains of central and southern Pakistan, which lie between 24°N - 32°N (Fawz-ul-Haq and Siddiqui, 1994). In this geographical layout, hybrid electric power plants located in the 'sun-rich' areas, generating electricity directly with solar induced up draft wind energy would be highly feasible. During the active sunny periods, along with electric power, hydrogen can be produced from the continuous supply of river water, which can be stored for use during the inactive periods. Different phases of the power-cycle and appropriate technologies are discussed below.

2. SOLAR THERMAL POWER PLANTS

In the economic and technical setup of Pakistan, the most appropriate method of tapping the vast solar energy reserve of the country appears to be the renewable 'Solar-Tower' power plants. One such plant of 200MW is being endeavored in Australia by M/S EnviroMission (http://www.enviromission.com.au/). Although, initially such plants are somewhat more expensive than the pollution-loaded oil/coal fired power plants, nonetheless the costs are comparable, with low recurrent expenditures and clean energy is the output (Badenwerk and EVS, 1997). In addition, such configurations offer (mostly) continuous power generation during non-sun periods as well. The technology is simple, reliable and accessible to the less industrialized countries that are sunny but may have limited fuel and raw materials resources. They do not require cooling water and offer environmentally sound production from renewable or recyclable materials. Such renewable clean energy, 'Solar Chimney or Tower' power plants utilize a combination of solar air collector and central updraft tube to generate a solar induced convective flow, which drives pressure staged turbines to generate electricity (see figure 1), Schlaich, et al. (2004).

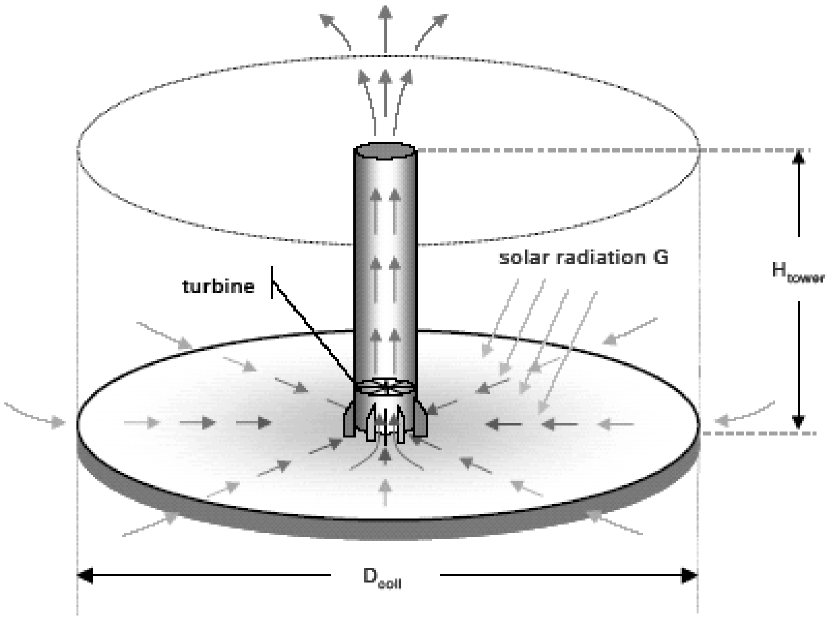

Figure 1: Solar Chimney or Tower configuration (Schlaich, et al., 2003)

2.1. Functional Principle of Solar-Thermal Up-Draft Power Plants

The solar 'up-draft' tower configuration has three major components: the collector zone (greenhouse), Solar Tower (chimney) and turbines (figure 1). 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 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 hours operation can be achieved by placing tight water-filled tubes or bags under the roof. The water heats up during day-time and releases its heat at night. 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, which drive conventional electricity generators (Schlaich and Schiel, 2001).

3. USING HYDROGEN AS A BACK-UP CLEAN ENERGY SOURCE

M/S EnviroMission, Limited, the builders of the Solar-Tower in Australia propose to generate electricity 24-hours a day. However, this would be possible only if there would be no long-duration weather systems blocking the sunshine. Hence such technology would not work in relatively cloudy but high solar insolation regions. To make its use more extensively, it is proposed to remedy the drawback of the above-mentioned system by incorporating Hydrogen gas as a back-up clean fuel.

In Pakistan, the Indus River water could be conveniently used to generate Hydrogen gas through photoelectrolysis. Many appropriate photoelectrolysis based hydrogen generation methods (see e.g., http://www.shec-labs.com/process.php) are being developed worldwide; one of them could be used as follows. The glass canopy of the shed (the large glass covered roof acting as a greenhouse collector) is embedded with a large number of solar concentrators for amplifying solar light at specific points on the floor underneath the canopy (figure 2). At these points, sufficiently small, covered pools of water are put up to generate hydrogen gas through photoelectrolysis (the collector roof is < 2 meters above the floor). The number of such light-concentrators and water-pools is the same. Since such solar concentrators are very small as compared to the huge canopy, a fairly large number can be accommodated. For example, in the Australian Solar-Tower endeavor of 200-MW, their proposed roof would have an area of about 20 sq. kms. If a solar concentrator is of 20-cm diameter, and 1% of the roof is covered with them, then the total number of such concentrators would be more than five million!

Additionally, such light-concentrators would be made to track the sun and always reflect the amplified light on the pools below. This would enable all-day reception of concentrated light in the pool, thereby heating its water to a high enough temperature to generate hydrogen.

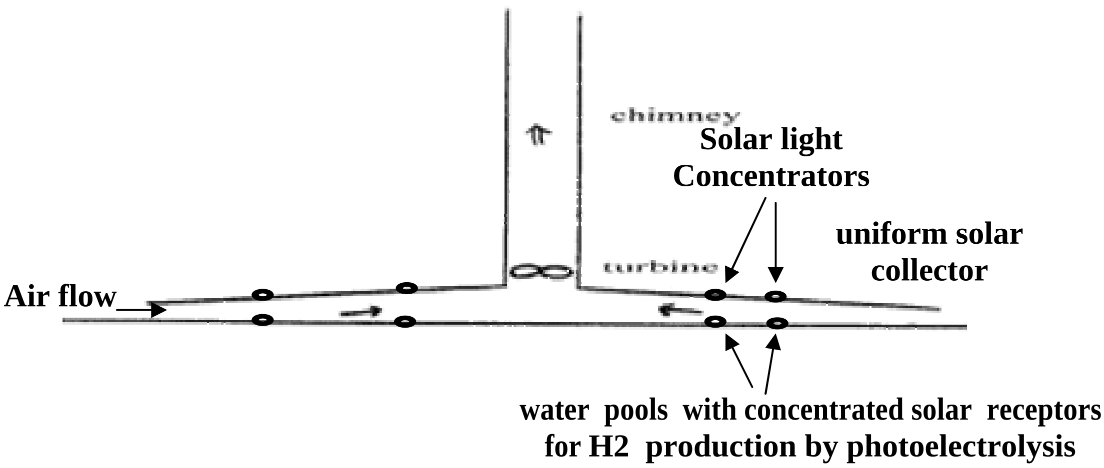

Figure 2. Hydrogen production by photoelectrolysis in the Solar (up-draft) Tower design

4. OTHER SUGGESTIONS TO IMPROVE FUNCTIONALITY

To make the above-mentioned scheme more efficient, it is suggested that,

- the floor underneath the canopy be made of solar radiation absorbing black material, to maximally absorb energy, thus increasing the wind speed. This would also enable a decrease in chimney height.
- For amplification of wind speed, the up-drafted air in the chimney pass through jet nozzle placed before/ beneath each turbine.
- The chimney height can be decreased by covering its top half with highly reflective material such as cheap aluminum sheets. The solar light reflected from the reflective covering inside the chimney would heat the air column in it, thereby decreasing the air pressure inside the (~150 meter wide) chimney. This would also facilitate an increase in the speed of the up-draft. Even then, the chimney should be sufficiently high, so that the escaping air draft is not affected by the heat-emitting roof of the collector (canopied base).
- During November-February period, the sun would be lower in the sky as compared to other months. The loss in the insolation can be remedied by putting a high enough reflective wall on the northern side of the canopied base. The wall can be sufficiently angled to reflect all solar light on the collector, which would include the solar light concentrators as well. This would also allow a decrease in chimney height.
- During abundant sunshine days, the excess hydrogen can be stored or transported in cylinders or pipelines.

5. DISCUSSION

The worldwide fossil fuel crisis is ever so increasing the importance of alternative renewable energy sources. Global warming and increases in pollution have put an additional constraint for the energy-source to be a clean one – that does not cause any increase in greenhouse gases in the atmosphere. Among such sources, Hydrogen turns out to be potentially the best and is available all over the earth!

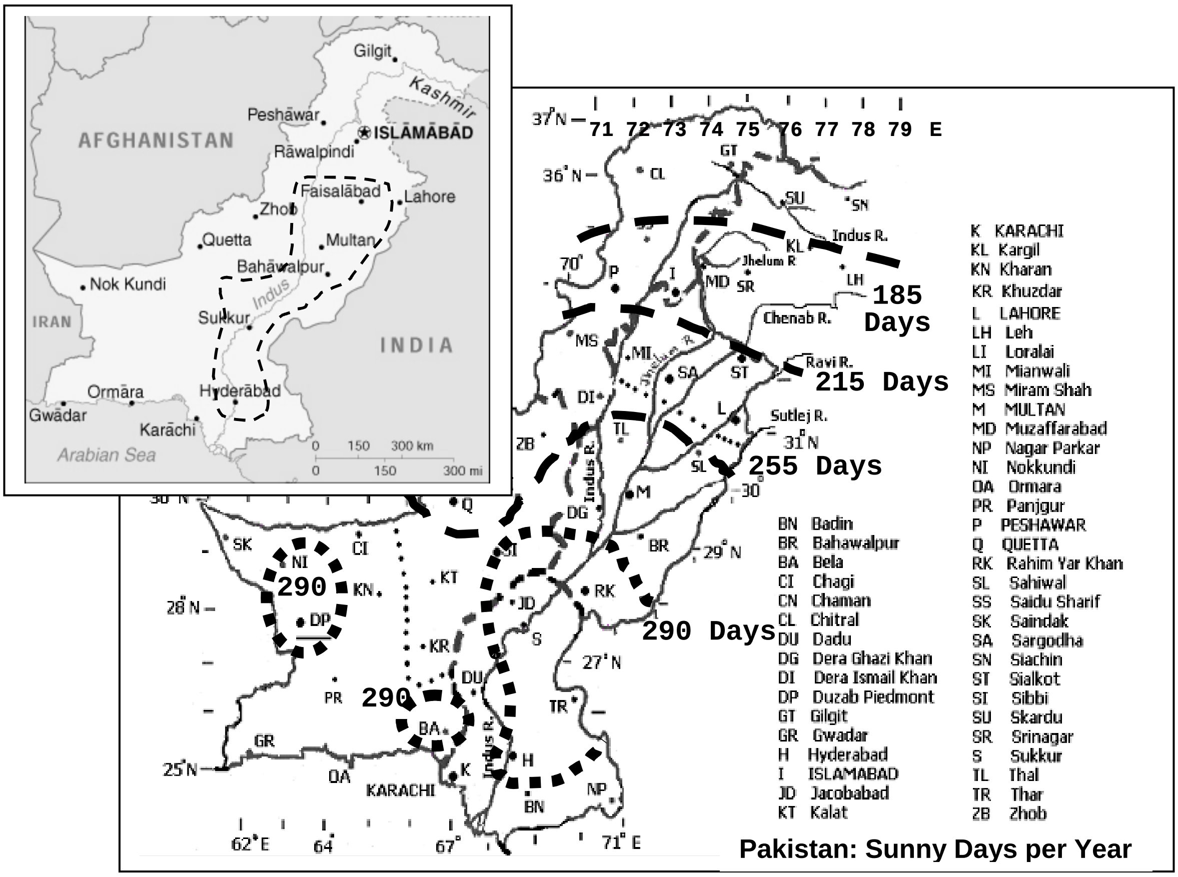

Figure 3. Thick lined dashed contours on the map of Pakistan show 'sunny-days per year', averaged over the period 1989-2002 (Fawz-ul-Haq, et al., 2003). In the top left corner the potential area is shown with dashed line, where 'Solar – Hydrogen' plants could be set up.

Pakistan has 18 gigawatts (GW) of electric generating capacity. Thermal plants using oil, natural gas, and coal account for about 70% of this capacity. Fossil fuels are fast depleting and Pakistan, which is heavily burdened in importing oil, has already made a large number of dams on its rivers. However, hydrogen and solar energy could be tapped easily, as given in the paper.

Pakistan's area is about 800,000 sq. kms; more than half of which is highly sunny, as well as sparsely populated. Considering the area, which also has abundant water, along with high insolation and low-cloudiness, the potentially useable area for generating solar-hydrogen in Pakistan would exceed ~150,000 sq. kms (see figure 3). Rough calculations show that less than 2% of this area could house more than 100 such plants of 200 MW each (assuming on the Australian pattern, one such power plant would cover less than 25 sq. kms.) producing more than 20 GW, with ample prospects for growth. Thus, the clean, renewable energy obtainable would be more than sufficient for the electricity needs of the whole country.

How much Hydrogen should each photoelectrolysis device produce? This relates to how much fossil fuel we want to replace! Since Pakistan is low on crude oil, which mainly is used in transportation and electricity generation, just replacing it is one measure. Presently Pakistan requires about 400,000 bbl/day. This is equivalent to 1.6 x 10^6 cubic meters of '150 bar Hydrogen gas' per day (1bbl crude oil = 4.06 cu.m. of H_2 at 150 bars). Of the 100 such power plants, if each houses five million small photoelectrolysis devices, then each device should be able to produce 0.004 cu.m. per day (4000 cubic centimeters per day) !

REFERENCES

Badenwerk AG and Energie-Versorgung Schwaben (EVS) AG. "Technische und wirtschaftliche Aspekte zur Beurteilung der Chancen von Aufwindkraftwerken", Internal Report, Karlsruhe/ Stuttgart. (1997)

Fawz-ul-Haq, K.R., and Siddiqui, Z.R.: Identifying Potential Solar Power Generation Sites Using Satellite APT Images. Advances in Space Research, Vol. 14, No.1, pp. (1)243-(1)246. (1994)

Fawz-ul-Haq, K.R., Munir S., Farooqui, Y. and Javed, A..: Monitoring of Drought Condition over Pakistan through Satellite Based Cloud-Cover Data" SUPARCO Internal Final Report (2003).

Schlaich, J. and Schiel, W.. "Solar Chimneys", *Encyclopedia of Physical Science and Technology*, 3rd Edition, Academic Press, London. (2001)

Schlaich, J., Bergermann, R., Schiel W., Weinrebe, G.: Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flows for Power Generation, http://www.thedunngeon.com/The_Solar_Updraft%20Plan.pdf (2004)