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Redesign and Fabrication of Solar Power Tower using CAD and FEM Analysis

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Abstract: *The solar power tower (also known as 'Central Tower' power plants or 'Heliostat' power plants or power towers) is a type of solar furnace using a tower to receive the focused sunlight. It uses an array of flat, moveable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target). The high energy at this point of concentrated sunlight is transferred to a substance that can store the heat for later use. The more recent heat transfer material that has been successfully demonstrated is liquid sodium. Sodium is a metal with a high heat capacity, allowing that energy to be stored and drawn off throughout the evening. That energy can, in turn, be used to boil water for use in steam turbines. Water had originally been used as a heat transfer medium in earlier power tower versions (where the resultant steam was used to power a turbine). This system did not allow for power generation during the evening.*

Keywords: *Heliostats Attachment, Collector Tower, Liquid Sodium, Power a Turbine.*

I. Introduction

To date, the largest power towers ever built are the 10 MW Solar One and Solar Two plants. Assuming success of the Solar Two project, the next plants could be scaled-up to between 30 and 100 MW in size for utility grid connected applications in the Southwestern United States and/or international power markets. New peaking and intermediate power sources are needed today in many areas of the developing world. India, Egypt, and South Africa are locations that appear to be ideally suited for power tower development. As the technology matures, plants with up to a 400 MW rating appear feasible.

As non-polluting energy sources become more favored, molten-salt power towers will have a high value because the thermal energy storage allows the plant to
be dispatch able. Consequently, the value of power is worth more because a power tower plant can deliver energy during peak load times when it is more valuable. Energy storage also allows power tower plants to be designed and built with a range of annual capacity factors (20 to 65%). Combining high capacity factors and the fact that energy storage will allow power to be brought onto the grid in a controlled manner (i.e., by reducing electrical transients thus increasing the stability of the overall utility grid); total market penetration should be much higher than an intermittent solar technology without storage.

One possible concern with the technology is the relatively high amount of land and water usage. This may become an important issue from a practical and environmental viewpoint since these plants are typically deployed within desert areas that often lack water and have fragile landscapes. Water usage at power towers is comparable to other Rankine cycle power technologies of similar size and annual performance. Land usage, although significant, is typically much less than that required for hydro [3] and is generally less than that required for fossil (e.g., oil, coal, natural gas), when the mining and exploration of land are include

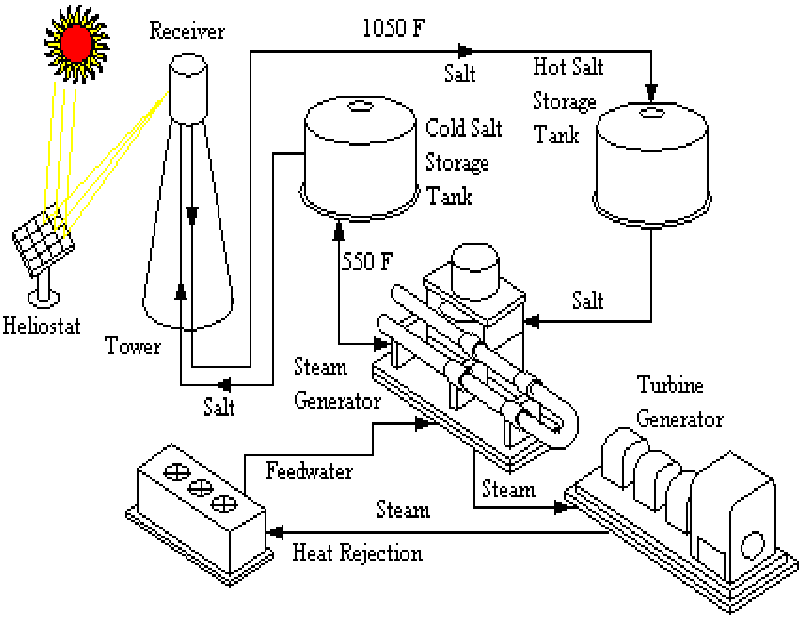

Fig.1 Overview Design of Solar power collector.

A better approach to the prediction of welding deformation is using the combined technologies of experiments with numerical calculation. With modern computing facilities, the Finite Element (FEM) technique has become an effective method for prediction and assessment of solar residual stress and distortions various factors, the quantitative prediction and the control of Solar deformation especially for a large and complex welded structure is extremely difficult.

Each of the mirrors has a surface measuring 120 m² (1,292 square feet) that concentrates the sun's rays to the top of a 115 meter (377 ft) high, 40-story tower where a solar receiver and a steam turbine are located. The turbine drives a generator, producing electricity.

II. Brief Overview of System Description

Solar power towers generate electric power from sunlight by focusing concentrated solar radiation on a tower-mounted heat exchanger (receiver). The system uses hundreds to thousands of sun-tracking mirrors called heliostats to reflect the incident sunlight onto the receiver. These plants are best suited for utility-scale applications in the 30 to 400 MWe range. In a molten-salt solar power tower, liquid salt at 290ºC is pumped from a 'cold' storage tank through the receiver where it is heated to 565ºC and then on to a 'hot' tank for storage. When power is needed from the plant, hot salt is pumped to a steam generating system that produces superheated steam for a conventional Rankin cycle turbine/generator system. From the steam generator, the salt is returned to the cold tank where it is stored and eventually reheated in the receiver. Figure 1 is a schematic diagram of the primary flow paths in a molten-salt solar power plant. Determining the optimum storage size to meet power-dispatch requirements is an important part of the system design process. Storage tanks can be designed with sufficient capacity to power a turbine at full output for up to 13 hours.

The heliostat field that surrounds the tower is laid out to optimize the annual performance of the plant. The field and the receiver are also sized depending on the needs of the utility. In a typical installation, solar energy collection occurs at a rate that exceeds the maximum required to provide steam to the turbine. Consequently, the thermal storage system can be *charged* at the same time that the plant is producing power at full capacity. The ratio of the thermal power provided by the collector system (the heliostat field and receiver) to the peak thermal power required by the turbine generator is called the solar multiple.

Fig.2 Overview Design of Solar power collector.

III. Rankine Cycle

There are four processes in the Rankine cycle, each changing the state of the working fluid. These states are identified by number in the diagram above.

- **Process 4-1**: First, the working fluid is pumped (ideally isentropic ally) from low to high pressure by a pump. Pumping requires a power input (for example mechanical or electrical).
- **Process 1-2**: The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a superheated vapor. Common heat sources for power plant systems are coal, natural gas, or nuclear power.
- **Process 2-3**: The superheated vapor expands through a turbine to generate power output. Ideally, this expansion is isentropic. This decreases the temperature and pressure of the vapor.

- **Process 3-4**: The vapor then enters a condenser where it is cooled to become a saturated liquid. This liquid then re-enters the pump and the cycle repeats.

Rankine cycles describe the operation of steam heat engines commonly found in power generation plants. In such vapor power plants, power is generated by alternately vaporizing and condensing a working fluid (in many cases water, although refrigerants such as ammonia may also be used).

The working fluid in a Rankine cycle follows a closed loop and is re-used constantly. Water vapor seen billowing from power plants is evaporating cooling water, not working fluid.

IV. Energy Storage

The PS10 solar power tower stores heat in tanks as superheated and pressurized water at 50 bar and 285 °C. The water evaporates and flashes back to steam, releasing energy and reducing the pressure. Storage is for one hour. It is suggested that longer storage is possible, but that has not been proven yet in an existing power plant. However, there are many considerations for using molten salt as an energy storage medium due to the great capability of storing energy for long periods of time without substantial losses. Another possibility is to use a phase-change material as thermal storage where latent heat is used to store energy.

V. Heliostat

It comes from Helios, the Greek word for sun and stat, as in stationary. A Heliostat is a device that tracks the movement of the sun. It is typically used to orient a mirror, throughout the day, to reflect sunlight in a consistent direction. When coupled together in sufficient quantities, the reflected sunlight from the heliostats can generate an enormous amount of heat if all are oriented towards the same target. It was originally developed as an instrument for use in surveying, allowing the accurate observation of a known point from a distance. Heliostats have been used for sunlight-powered interior lighting, solar observatories, and solar power generation. Mirrors and reflective surfaces used in solar power that do not track the sun are not heliostats.

The simplest heliostat devices use a clockwork mechanism to turn the mirror in synchronization with the rotation of the Earth. More complex devices need to compensate for the changing elevation of the Sun throughout a Solar year. Even more advanced heliostats track the sun directly by sensing its position throughout the day. The heliostat reflects the sunlight onto the transmission system. This is typically a set of mirrors that direct the reflected sunlight into the building or, alternatively, a light tube. Fiber optic cabling has also been used as a transfer mechanism. Various forms of commercial products have been designed for the point of termination (the "light bulb").

Fig.3 Heliostat Device for Solar power collector

The heliograph had some great advantages. It allowed long distance communication without a fixed infrastructure, though it could also be linked to make a fixed network extending for hundreds of miles, as in the fort-to-fort network used for the Geronimo campaign. It was very portable, did not require any power source, and was relatively secure since it was invisible to those not near the axis of operation, and the beam was very narrow, spreading only 50 feet per mile of range. However, anyone in the beam with the correct knowledge could intercept signals without being detected. In the Boer war, where both sides used heliographs, tubes were sometimes used to decrease the dispersion of the beam. Conversely, the narrow beam made it very difficult to stay aligned with a moving target, as when communicating from shore to a moving ship, and the British issued a dispersing lens to broaden the heliograph beam from its natural diameter of 0.5 degrees to 15 degrees for that purpose.

The distance that heliograph signals could be seen depended on the clarity of the sky and the size of the mirrors used. A clear line of sight was required, and since the Earth's surface is curved, the highest convenient points were used. Under ordinary conditions, a flash could be seen 30 miles (48 km) with the naked eye, and much farther with a telescope. The maximum range was considered to be 10 miles for each inch of mirror diameter. Mirrors ranged from 1.5 inches to 12 inches or more. The record distance was established by a detachment of U.S. signal sergeants by the inter-operation of stations on Mount Ellen, Utah, and Mount Uncompahgre, Colorado, 183 miles (295 km) apart on September 17, 1894, with Signal Corps heliographs carrying mirrors only 8 inches square. A **heliostat** (from *helios*, the Greek word for *sun*, and *stat*, as in stationary) is a device that includes a mirror, usually a plane mirror, which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky. The target may be a physical object, distant from the heliostat, or a direction in space. The alt-azimuth and polar-axis alignments are two of the three orientations for two-axis mounts that are, or have been, commonly used for heliostat mirrors.

VI. Tracking Alternatives

The movement of most modern heliostats employs a two-axis motorized system, controlled by computer as outlined at the start of this article. Almost always, the primary rotation axis is vertical and the secondary horizontal, so the mirror is on an alt-azimuth mount. One simple alternative is for the mirror to rotate around a polar aligned primary axis, driven by a mechanical, often clockwork, mechanism at 15 degrees per hour, compensating for the earth's rotation relative to the sun. The mirror is aligned to reflect sunlight along the same polar axis in the direction of one of the celestial poles. There is a perpendicular secondary axis allowing occasional manual adjustment of the mirror (daily or less often as necessary) to compensate for the shift in the sun's declination with the seasons. The setting of the drive clock can also be occasionally adjusted to compensate for changes in the Equation of Time. The target can be located on the same polar axis that is the mirror's primary rotation axis, or a second, stationary mirror can be used to reflect light from the polar axis toward the target, wherever that might be. This kind of mirror mount and drive is often used with solar cookers, such as Scheffler reflectors. For this application, the mirror can be concave, so as to concentrate sunlight onto the cooking vessel.

VII. Land, Water, and Critical Materials Requirements

The land and water use values provided in Table 4 apply to the solar portion of the power plant. Land use in 1997 is taken from Solar Two design documents. Land use for years 2000 and beyond is based on systems studies. The proper way to express land use for systems with storage is ha/MWh/yr. Expressing land use in units of ha/MW is meaningless to a solar plant with energy storage because the effect of plant capacity factor is lost. Water use measured at the SEGS VI and VII [20] trough plants form the basis of these estimates. Wet cooling towers are assumed. Water usage at Solar Two should be somewhat higher than at SEGS VI and VII due to a lower power block efficiency at Solar Two (33% gross). However, starting in the year 2000, water usage in a commercial power tower plant, with a high efficiency power block (42% gross), should be about 20% less than SEGS VI and VII. If adequate water is not available at the power plant site, a dry condenser-cooling system could possibly be used. Dry cooling can reduce water needs by as much as 90%. However, if dry cooling is employed, cost and performance penalties are expected to raise level zed-energy costs by at least 10%.

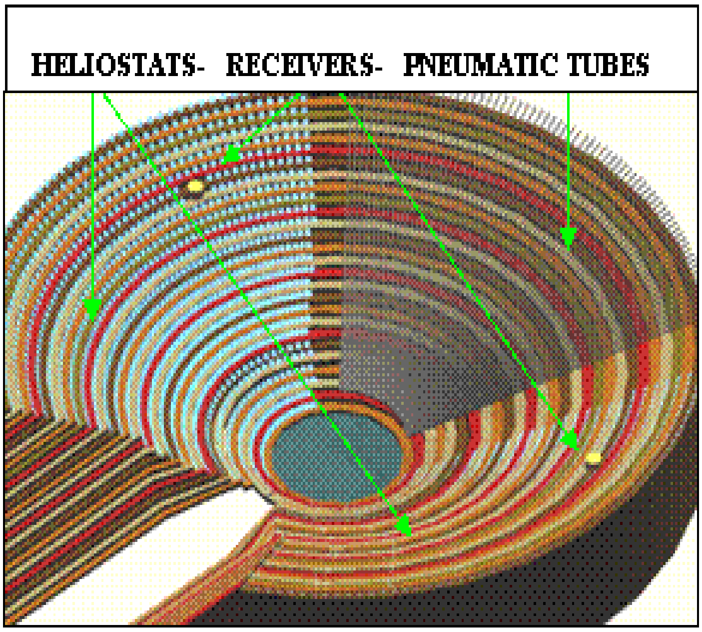

Fig.4 Roof-mounted Close-Coupled Heliostats Receivers

VIII. Solar Power Applications

Several kinds of very practical solar energy systems are in use today. The two most common are passive solar heated homes (or small buildings), and small stand-alone photovoltaic (solar electric) systems. These two applications of solar energy have proven themselves popular over a decade of use. They also illustrate the two basic methods of harnessing solar energy: solar thermal systems, and solar electric systems. The solar thermal systems convert the radiant energy of the sun into heat, and then use that heat energy as desired. The solar electric systems convert the radiant energy of the sun directly into electrical energy, which can then be used as most electrical energy is used today.

Fig.5 The Solar Bowl above the ground in Auroville, India concentrates sunlight on a movable receiver to produce heat for Electricity

Where temperatures below about 95 °C are sufficient, as for space heating, flat-plate collectors of the non concentrating type are generally used. Because of the relatively high heat losses through the glazing, flat plate collectors will not reach temperatures much above 200 °C even when the heat transfer fluid is stagnant. Such temperatures are too low for efficient conversion to electricity. During the day the sun has different positions. For low concentration systems (and low temperatures) tracking can be avoided (or limited to a few positions per year) if nonimaging optics are used. For higher concentrations, however, if the mirrors or lenses do not move, then the focus of the mirrors or lenses changes (but also in these cases nonimaging optics provides the widest acceptance angles for a given concentration). Therefore it seems unavoidable that there needs to be a tracking system that follows the position of the sun (for solar photovoltaic a solar tracker is only optional). The tracking system increases the cost and complexity. With this in mind, different designs can be distinguished in how they concentrate the light and track the position of the sun.

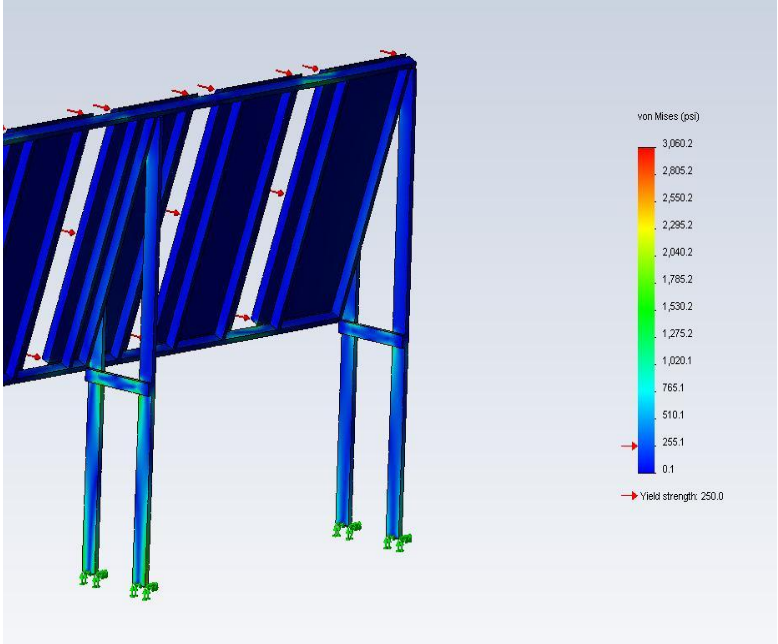

Fig.6 Solar Panels of Collectors FEM Analysis

The energy storage system for Solar Two consists of two 875,000 liter storage tanks which were fabricated on-site by Pitt-Des Moines. The tanks are externally insulated and constructed of stainless steel and carbon steel for the hot and cold tanks, respectively. Thermal capacity of the system is 110 MWh. A natural convection cooling system is used t in the foundation of each tank to minimize overheating and excessive dehydration of the underlying soil. All pipes, valves, and vessels for hot salt were constructed from stainless steel because of its corrosion resistance in the molten-salt environment. The cold-salt system is made from mild carbon steel. The steam generator system (SGS) heat exchangers, which were constructed by ABB Lummus, consist of a shell-and-tube super heater, a kettle boiler, and a shell-and-tube preheater. Stainless steel cantilever pumps transport salt from the hot-tank-pump sump through the SGS to the cold tank. Salt in the cold tank is pumped with multi-stage centrifugal pumps up the tower to the receiver. Solar Two is expected to begin routine daily power production in late 1997. Initial data collected at the plant show that the molten-salt receiver and thermal storage tanks should perform as predicted during the heat treatment.

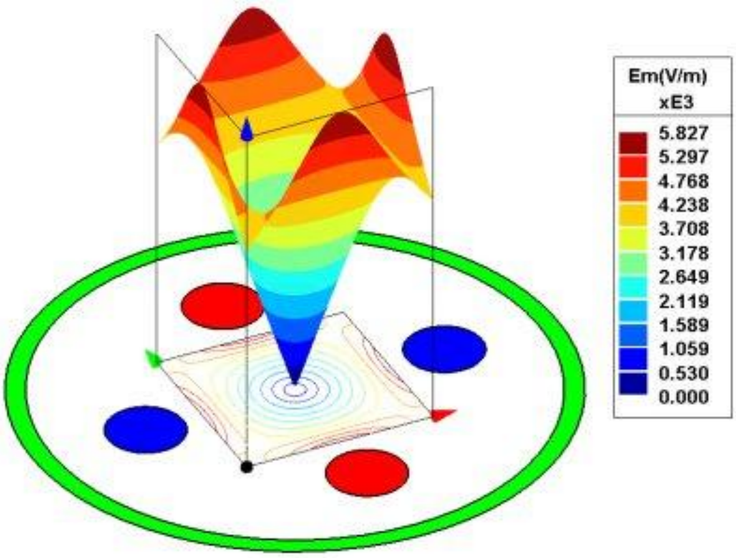

Fig.7 Results of Solar panels of FEM Analysis

The goals of the redesigned plant, called Solar Two, are to validate nitrate salt technology, to reduce the technical and Economic risk of power towers, and to stimulate the commercialization of power tower technology. Solar Two has produced 10 MW of electricity with enough thermal storage to continue to operate the turbine at full capacity for three hours after the sun has set. Long-term reliability is next to being proven. The conversion of Solar One to Solar Two required a new molten-salt heat transfer system including the receiver, thermal storage, piping, and a steam generator and a new control system. The Solar One heliostat field, the tower, and the turbine/generator required only minimal modifications. The Solar Two receiver comprises a series of panels (each made of 32 thin-walled, stainless steel tubes) through which the molten salt flows in a serpentine path. The panels form a cylindrical shell surrounding piping, structural supports, and control equipment.

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