CENTRAL RECEIVERS

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Contents

Summary

One way to utilize solar energy in the production of large-scale electric energy is to use central receiver systems. The present work introduces procedures to size two of the very important and vital subsystems in central receiver plants. The first subsystem is the heliostat field. In this field, several heliostats are laid in a given arrangement around a central receiver on top of a tower. Each heliostat rotates around two axes to continuously adjust the tilt and orientation angles of the heliostat to assure the reflection of the solar rays to the central receiver. The reflected energy from the field to the receiver suffers from several deficiencies. Among these deficiencies are the cosine effect of the position of the heliostat with respect to the receiver, the shadowing and blocking caused by the heliostats on one another, and the imperfection in the reflection

surface of the heliostats and their tracking mechanism. Therefore, the arrangement by which the heliostats are arranged around the tower and their spacing from one another greatly affect the amount of radiation that falls on the receiver. Procedure were given to layout the heliostats and to size their field for a given thermal MW that falls on the receiver. The second subsystem that we consider here is the receiver subsystem. The type, size and geometry of the receiver are factors that greatly contribute to the initial and operating costs of the central receiver plants. Procedures are given here to estimate the solar flux density on the receiver surface, the thermal losses from it and its size.

1. Introduction

Central receivers are one of the most promising applications in the utilization of solar energy to produce electric power on a large scale. Basically, reflecting surfaces called heliostats are laid around a central tower where they reflect solar irradiance to a receiver on the top of the tower. The radiation absorbed by the receiver is then utilized to produce electric power.

The operation of the central receiver systems is best explained by the photograph (Figure 1, Skinrood 1982). Generally, the central receiver system consists of the following major subsystems: the heliostat subsystem, the tower-receiver subsystem, the control subsystem, the thermal storage subsystem and the power generation subsystem.

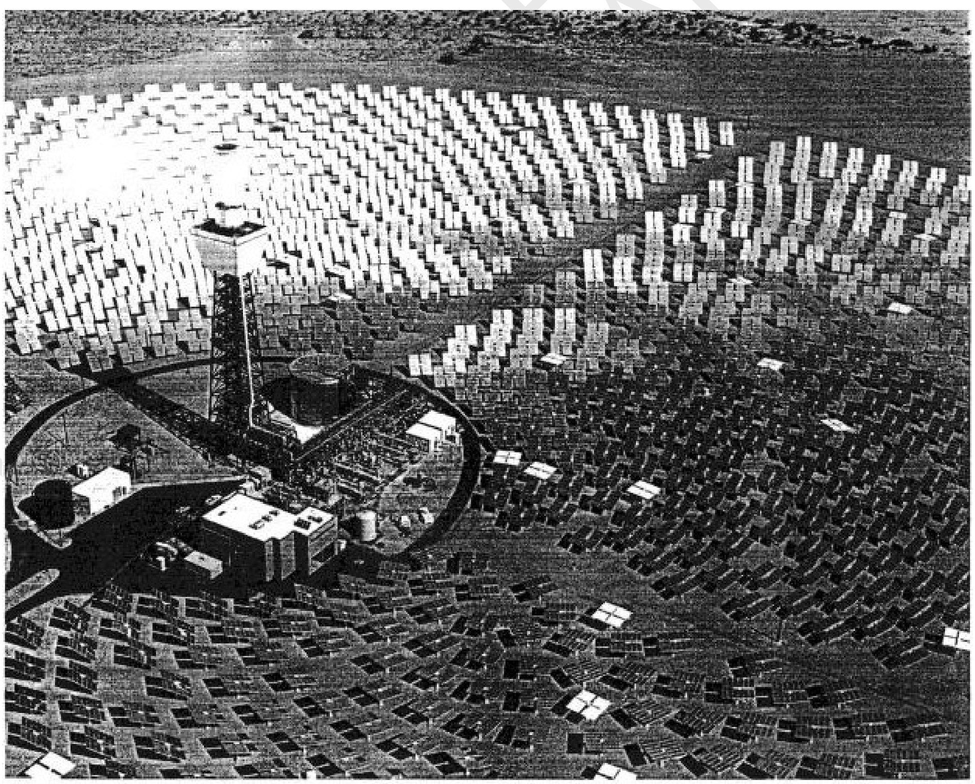

Figure 1. Photograph of the 10 MW central receiver pilot plant at California, USA.

The heliostat field consists of a large number of flat or focusing mirrors (heliostats) distributed with a given pattern around the central tower. The heliostats can be either distributed on one side of the receiver (the north side in the northern hemisphere), or in a surround-field arrangement (360° layout). The surround field arrangement is most suitable for large scale power applications. Each heliostat is continuously rotating around two axes to follow the sun as it moves so that solar rays are always reflected to the central receiver. This means that the tilt and the orientation angles of each heliostate are continuously adjusted. The reflected radiation from the heliostat field is absorbed by the receiver surface. Heat is then removed from the receiver by means of heat removal fluid and is transferred to a thermal storage tank. Heat from the storage tank is utilized to generate steam in a boiler and this steam is supplied to a turbine coupled to a generator for electric power generation. In some designs steam is generated directly in the receiver at the top of the tower.

Figures 2 and 3 depict two examples of power generation through the use of central receiver systems (Curto and Stern 1982). In the first example (Figure 2), molten salt is used as the heat removal fluid together with a power plant operating in a Rankine cycle. In the second example (Figure 3), air is directly heated in the receiver and used in a Brayton gas power cycle to produce electric power.

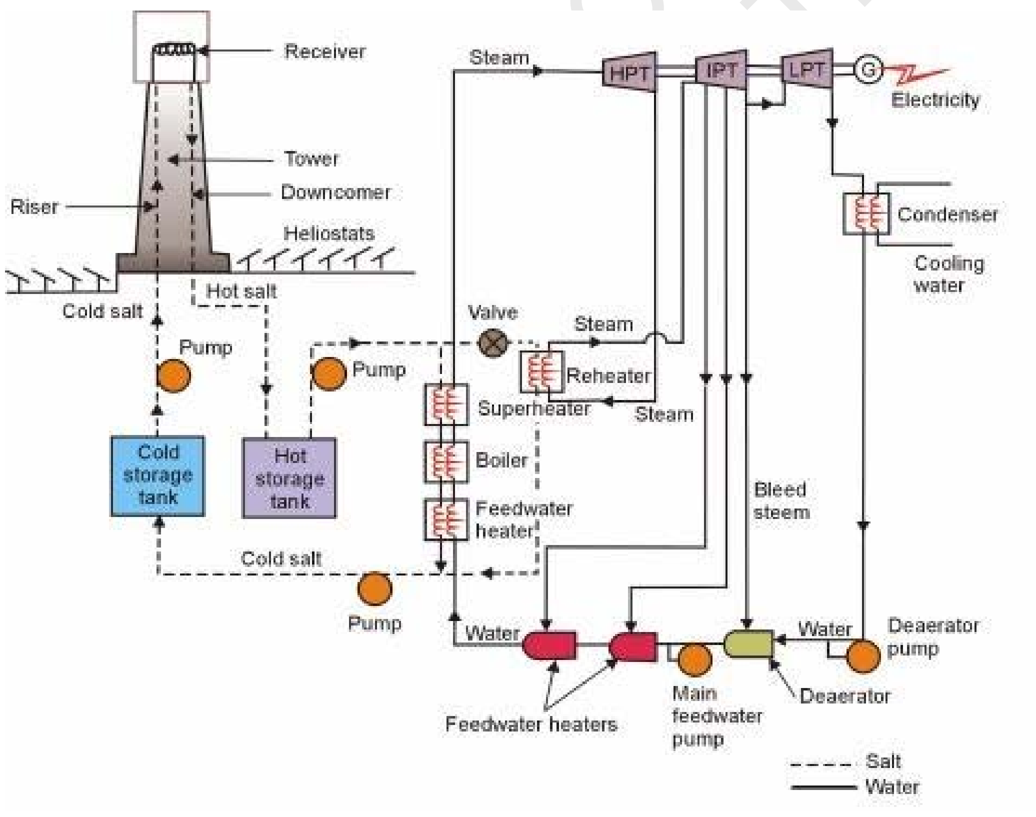

Figure 2. Molten salt central receiver system for power generation using a reheat steam cycle.

Although the central receiver systems are originated for power generation through the utilization of solar energy, these systems may also be employed in other fields.

Applications which require high concentrated heat flux are excellent examples. Among these applications are the production of fuels and chemicals through the integration with thermochemical or photochemical conversions schemes (Gupta 1984). Other applications also include those industries which require high temperature air such as of nickel, copper, zinc, lead and steel industries (Curto and Stern 1982).

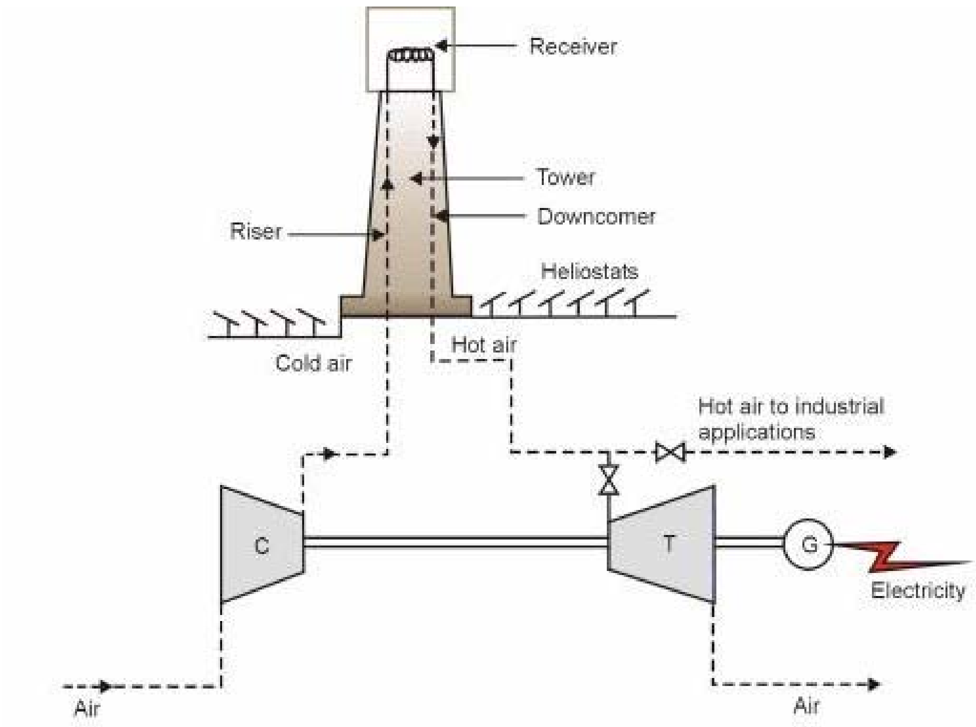

Figure 3. Forced air central receiver system for Brayton cycle power generation and/or industrial applications.

The overall dimensions and cost of a central receiver system depend on the design output of the system. To understand these dimensions and cost, consider the system shown in Figure 1 which is for the 10 MWe central receiver pilot plant at Barstow, California (USA). The heliostat field consists of 1818 focusing heliosts each of 39.3 m^2. The tower height is 90 m. The receiver is cylindrical in shape with a diameter of 7 m and total surface area for radiation collection of 325 m^2. The total cost of the plant in 1981 was $141.5 million.

The designer of a central receiver system faces several problems and challenges to economically optimize his design. Among these challenges are: the selection of the heliostat type: i.e. whether to be flat or focusing mirror; the dimension of each heliostat; the spacing between the heliostats in the field; the field dimensions; the tower height; the receiver geometry and type; the method of heat removal from the receiver; etc. In the following subsections, a review is carried out to identify the numerous design problems and challenges involved in the designing of a central receiver system. When available, design approaches are presented to overcome some of these problems and challenges.

2. Heliostats: Types and Design Shapes

The heliostat is a reflecting surface which is laid on the ground at a distance from the central tower, and is used to reflect solar radiation to the receiver at the top of the tower. For this reason each heliostat is continuously rotated around two axes to follow the motion of the sun. The heliostat has either a flat (non-focusing) or a focusing surface. In most cases glass mirrors are used as the reflecting surface. The heliostat usually consists of several segments (facets) for precise redirection of solar rays and easy handling; replacement and manufacturing of the reflecting surface. Figure 4 shows a flat (non-focusing) heliostat (Bartel and Skvarna 1984).

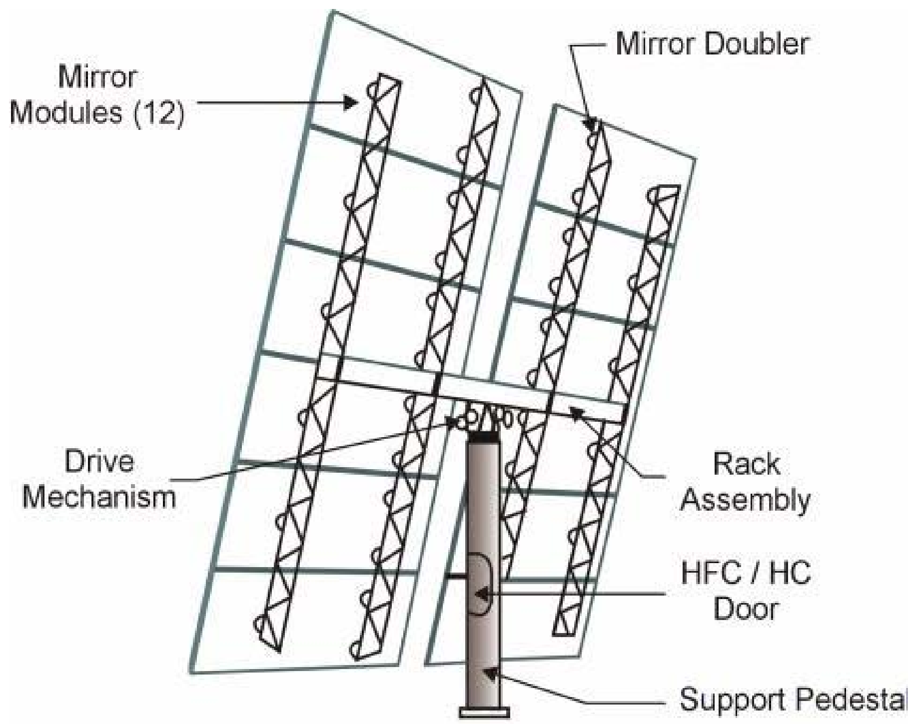

Figure 4. Heliostat configuration.

The solar limb angle, i.e. the angle between solar rays, causes the dimension of the reflected solar image on the receiver surface to increase as the heliostat is moved away from the tower. This leads to what is known as the spillage of the reflected image when its dimensions exceed that of the receiver. For this reason focusing heliostats are used to overcome the spillage problem of the reflected solar image. The focal length of each heliostat is taken equal to the distance between the reflecting surface and the receiver.

Several techniques may be adopted to continuously adjust the tilt and orientation of the reflecting surface. In one technique a sensor is used in a feedback circuit to adjust the angles of the heliostat, see Figure 5 (Hirono and Horigome 1984). Another technique is to use a software computer package to control the heliostat angles. A computer program used for this purpose in an experimental facility is given by Elsayed et al. (1993).

The field of heliostats is the most expensive part of central reviewer plants. For this reason the cost of the heliostats must be as low as possible for the technology to be commercially viable. Continuous efforts are being made to reduce the cost of glass mirrors. This includes the combination of improved design and the increase in the heliostat sizes. Glass mirror heliostats with reflective areas of 150 m^2 have been built and found to give good performance (Alpert and Houser 1989). To further reduce the cost a new innovative concept should be introduced.

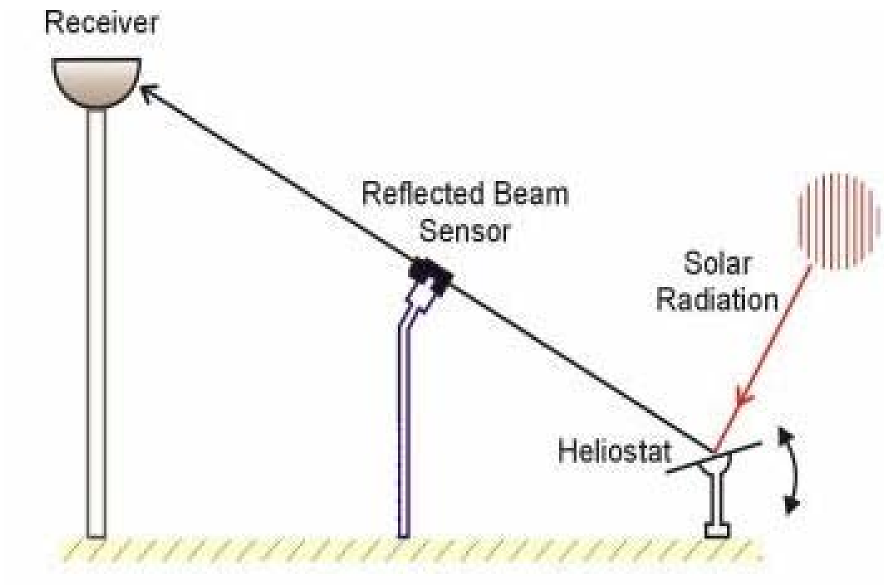

Figure 5. Reflected beam sensor to adjust the heliostat angles to track the sun.

The stretched membrane is a new innovative technique for manufacturing focusing heliostats. In this technique the reflector surface (aluminum for example) is stretched by slight vacuum. The stretched membrane technique has the advantage of providing a nearly perfect reflected image, low cost, less irregularities and lightweight (Kreith and Meyer 1984). The evaluation of the optical performance of the stretched membrane heliostat is as good as that of the glass-mirror design (Alpert and Houser 1989). The application of composite materials to stretched-membrane heliostat design is investigated by Kiang and Dharan (1989).

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