Abstract

Among the various avenues available to meet the energy demand, concentrated solar thermal technologies (CSTT) has gain its prominence recently. In CSTT, the design of heliostat field with central receiver (kept at the top of the tower) is a challenging task, as increasing the concentration of solar radiation onto a receiver leads to higher temperature and also, extracting energy efficiently from the receiver. Due of the continuous motion of the Sun, heliostat on ground should track the motion of the sun by employing two-axis tracking system throughout the year, which adds to its complexity. The design parameters of a heliostat field include the chosen size of the heliostat, heliostat position, tower height and aperture of the receiver, receiver efficiency, while variation in operation parameter namely operating temperatures, efficiencies of a heat exchangers, storage devices and the power block. Optical losses, namely: Shadowing and Blocking (S&B) effect, atmospheric attenuation, cosine loss and intercept factors contribute to heliostat field efficiency, which necessitates heliostat coordinates to be chosen appropriately. We estimate, position of Sun (Sun coordinates) for a given geographical location (Jodhpur, Coordinates: 26.24 N, 73.20 E), shadow coordinates and heliostat coordinates, which are vital for designing a heliostat field. To quantify the amount of radiation reaching the receiver unambiguously a ray tracing technique was used in this investigation. The chosen heliostat dimensions were 5 m x 5 m & 4 m x 4 m, the average ray efficiency 0.7 and 0.72 for the entire day (27^{th} December) and estimated optical power reaching the receiver 3.9 MW and 3.2 MW, while number of heliostats employed were 40 and 50 respectively.

Recently, cavity receiver has attracted shown higher receiver efficiency and, in this investigation, a circular heliostat field was designed as to illuminate the receiver completely. A novel receiver design was chosen, with 181 heliostats having dimension 5 m x 5 m & 2 m x 2 m were investigated for entire day having ray efficiency 0.56 & 0.72 and power reaching the receiver were 2.8 MW & 13.7 MW respectively. A beam-down approach was investigated having a hyperboloid mirror (secondary mirror) at a height of 18 meter from the ground using the unique property of hyperboloid at an interval of one-hour (900 Hrs - 1700 Hrs) for a given day in all months. A non-imaging optics element was designed to increase the concentration at the receiver which leads higher temperature (a factor of 2) as well as reduced receiver size. Along with radial staggered method and corn-field method were used for heliostat layout, while receivers were flat receiver, bladed receiver and cavity receiver were investigated. Using a designed 40 heliostats having heliostat dimension of 8 m x 8 m was introduced to generate 1.4 MWh and while 100 kWh can be generated using heliostat size of 2.5 m x 2.5 m (quantity: 50). A correlation between dimension of the heliostat and optical efficiency were observed in heliostat field design. The rotation angle(s) provided to individual heliostat for tracking the Sun were computed systematically as the reflected ray reaches the receiver. Using these angles, Euler angles as function of the matrix elements for the applied rotation sequence and its relation to quaternions as a function of Euler angles were also calculated in this work.

The stagnation temperature of the receiver was estimated using the concentration of radiation on it. Temperature contours were noted on the receiver based on intensity map using ray tracing. This provides the crucial information about the non-uniform temperature zone and its relative gradient present in the receiver, providing a valuable information about the possible hot-spot on the receiver, which helps in protecting it from the thermal damage. It is proposed that using infrared prediction tool PYRADI®, the temperature of receiver which would be estimated with the suitable choice of the detector along with optical components kept at the ground, thus estimating the radiative losses from the central receiver during the operational hours .