Cosine efficiency distribution of heliostats field of solar thermal power tower plants

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Abstract—Mathematical model of cosine efficiency of heliostats field of solar thermal power tower plants was established, while the distribution of cosine efficiency of traditional and rotating heliostats field for latitude of 40.4° in the northern hemisphere defined by essential staggering layout with no blocking radial spacing was analyzed. The results show that, at given condition, the incident angles for traditional tracking heliostats during equinox are comparatively smaller, and from 8 a.m. to 16 p.m., the zone of higher cosine efficiency moves from northwest side to northeast side, and the distribution at 12 o’clock is quite similar to that of the average level of whole working hours, choosing equinox noon as layout point for the traditional heliostats field is therefore a good first choice. However, the rotating heliostats field is more powerful in concentrating solar energy for higher cosine efficiency at almost any individual hours than that of the traditional field. While in common, the average cosine efficiency distribution of the traditional and rotational field is symmetrical along the north direction to the tower, while the collective performance is better for those heliostats with less azimuthal angles and with shorter distance to the receiver. Based on this principle, placement and maintenance strategy of heliostats should be made so as to collect more solar energy.

Keywords—solar thermal power tower; heliostats field; incident angle; cosine efficiency

I. INTRODUCTION

Solar thermal power is a great potential renewable energy technology, but has been delayed in market development since the 1980s, while now rapid growth in this field occurs both in technology, but has been delayed in market development since

Electricity Costs of solar thermal power tower system can be at about 5cents/kwh [2], which has a very promising market prospect.

In solar thermal power tower plants, incident sunrays are tracked by large mirrored collectors (heliostats) which concentrate the energy flux on the receiver which is mounted on top of a tower and where energy is transferred to a working thermal fluid. Although the general concept of the solar thermal power tower system is well known, the literature lacks information for proper heliostats distribution and maintenance strategy around the tower, which could be a very detrimental factor in the amount of energy collected and the capital costs invested. Improper heliostat layout results in excessive losses such as cosine effect, blocking, shadowing, etc. Among these losses, it can be deduced from references [3-5] that cosine loss takes the portion of as great as 50%-70% as the result of

II. CALCULATION OF COSINE EFFICIENCY OF HELIOSTAT

As shown in Figure 1, x axis points to the east, y axis points to the south and z axis points to the zenith.

The incident rays depend on the position of the sun, which is described by three basic angles: solar hour angle \( \omega \), site latitude \( \varphi \) and solar declination \( \delta \) as follows

\[
\sin \alpha_s = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos \omega \quad (1)
\]

\[
\delta = 23.45 \sin(360 \times \frac{284 + n}{365}) \quad (2)
\]

Where \( n \) is day number, \( n=1 \) is January 1st.

\[
\cos \gamma_s = \frac{\sin \alpha_s \sin \varphi - \sin \delta}{\cos \alpha_s \cos \varphi} \quad (3)
\]

In these coordinates, the direction of the incident sun rays can be expressed by unit vector \( \vec{I} \)

\[
(\cos \alpha_s \sin \gamma_s, -\cos \alpha_s \cos \gamma_s, -\sin \alpha_s) \quad (4)
\]

If aim point height is \( h_v \), the elevation of the heliostat and the height of the tower base are both \( h_h \), for the coordinates of heliostat (x, y, h_h) and the coordinates of the target point (0, 0, \( h_v + h_h \)), the unit vector of reflective rays is defined as \( \vec{R} \)

\[
(\frac{-x}{\sqrt{x^2 + y^2 + h_h^2}}, \frac{-y}{\sqrt{x^2 + y^2 + h_h^2}}, \frac{h_v}{\sqrt{x^2 + y^2 + h_h^2}}) \quad (5)
\]