

Contents

	<i>Page</i>
Declaration	Iii
Certificate	V
Acknowledgements	Vii
Contents	Ix
List of Figures	Xiv
List of tables	Xvi
List of Symbols	Xvii
List of Abbreviations	Xviii
Abstract	20
Chapter 1 : Introduction	23 – 36
1.1 Motivation of work	23
1.2 Photovoltaics and Solar thermal	23
1.3 Solar thermal and other renewable sources of energy	24
1.4 Concentrated Solar Plants (CSP) Tower	24
1.5 Software and relevant Codes for Analysis of Concentrating Solar Power Technologies	27
1.6 Objective of work	30
1.7 Justification of work	30
1.8 Solar Thermal Energy generation, the Indian story	31
1.8.1 National Review	31
1.9 The research gap areas in the heliostat field design using optical ray tracing approach	32
1.9.1 General review regarding Solar Thermal Power in India	35
1.10 Outline of this thesis	36
Chapter 2 :Optics, related Thermodynamics ,Ray tracing and SunShape	37 – 54
2.1 Earth Sun Geometry	37
2.1.1 Declination angle (δ)	
2.1.2 Equation of time (EOT) and Hour angle (ω)	
2.1.3 Latitude (Ψ) and Longitude angle	
2.1.4 Elevation /Altitude angle α and Azimuth angle Φ	
2.2 Radiation from the Sun	41
2.2.1 Solar Constant	42
2.3 Ray Tracing	43
2.3.1 Ray Tracing by Computer	
2.3.2 Eikonal equation	
2.3.3 Monte Carlo Ray tracing (MC) in Tracepro	

2.4	Sun Shape	50
	2.4.1 Brief discussion on the software and their literature performance	
2.5	Exergy and its connect with temperature	52
Chapter 3 :Concentrating Solar Power (CSP) field, Losses and Mathematics involved		55 – 99
3.1	Heliostats and CSP field design	55
	3.1.1 Heliostats	
3.2	Beam Up technology	58
	3.2.1 Line focus technology	
	3.2.1.1 Parabolic Trough (PT) ^l	
	3.2.1.2 Linear Fresnel Reflector (LFR)	
	3.2.2 Point focus technology	
	3.2.2.1 Power Tower	
	3.2.2.2 Parabolic dish-Engine	
3.3	Beam Down technology	62
	3.3.1 Inclined Plane (IP)	
	3.3.2 Conic section	
	3.3.2.1 Hyperboloid as secondary mirror	
	3.3.2.2 Ellipsoid	
	3.3.2.3 Comparison between Hyperboloid and Ellipsoid as SR	
3.4	Optical field design	67
3.5	Spatial orientation of the Heliostat field	68
	3.5.1 Radial Staggered (RS)	
	3.5.2 Cornfield	
	3.5.3 Sunflower	
3.6	Receiver	71
	3.6.1 Flat receiver	
	3.6.2 Cavity receiver	
	3.6.3 Bladed receiver	
	3.6.4 Cylindrical Receiver	
3.7	Angular orientation of the Heliostat	76
	3.7.1 Azimuth - Elevation (AE) method	
	3.7.2 Spinning - Elevation (SE) method	
3.8	Losses involved and aberrations in the Optical field	76
	3.8.1 Losses related to solar field setup	
	3.8.1.1 Shadowing	
	3.8.1.2 Blocking (η_B)	
	3.8.1.3 Cosine factor (η_F)	
	3.8.1.4 Reflectance (η_R)	
	3.8.1.5 Atmospheric attenuation (η_A)	

	3.8.1.6 Spillage	
	3.8.2 Losses related to solar field setup	
	3.8.2.1 Spherical Aberration	
	3.8.2.2 Coma	
	3.8.2.3 Distortion	
	3.8.2.4 Optical Astigmatism	
	3.8.2.5 Curvature of field	
	3.8.3 Losses related to Optical field setup	
	3.8.3.1 Slope errors	
	3.8.3.2 Specularity errors	
3.9	Mathematics involved for generation of field layout	86
	3.9.1 Solar spatial coordinates	
	3.9.2 Solar angular coordinates	
	3.9.3 Heliostat spatial coordinates	
	3.9.3.1 Radial Staggered	
	3.9.3.2 Cornfield	
	3.9.3.3 Sunflower	
	3.9.4 Heliostat angular coordinates	
	3.9.4.1 Eulerian angles	
	3.9.4.2 Quaternions	
	3.9.5 Heliostat curvature	
	3.9.5.1 Conic section	
	3.9.5.1 Hyperboloid equation used for Beam Down geometry	
	3.9.5.2 Ellipsoid equation used for Beam Down geometry	
3.10	Non-Imaging optics (NIO)	95
	3.10.1 Advantages of NIO for solar energy concentration	
	3.10.2 Edge-Ray algorithm to generate a CPC	
	3.10.3 Invariance, Etendue and Solar Concentration	
	3.10.4 Geometrical Concentration Factor (GCF)	
Chapter 4 : Ray tracing work performed		100-138
4.1	Solar angles and Shadow map	102
	4.1.1 Solar angles	
	4.1.2 Shadow mapping	
	4.1.3 Typical Meteorological Year (TMY) and Daily Normal Irradiance (DNI)	
4.2	Beam up	103
	4.2.2.1 Generation of field of capacity of 100 Kw power	
	4.2.2.2 Generation of field of capacity 1.4 MW power	
	4.2.3 Cornfield	
	4.2.4 Estimation and optimization of heliostat field for 400 kW to 550 kW optical power using ray tracing method.	
	4.2.5 A novel uniform illumination on receivers in central tower systems using ray tracing approach	
	4.2.6 Ray Tracing Approach for the Performance Evaluation of Bladed and Flat-Plate Receiver in Central Tower Systems	

	4.2.7 Sunflower geometry	
4.3	Beam Down	123
	4.3.1 Inclined plane as secondary mirror.	
	4.3.2 Hyperboloid as secondary mirror	
	4.3.3 Ellipsoid as secondary mirror	
	4.3.4 Use of CPC together with conic geometry for Beam Down work	
4.4	Comparative study	133
	4.4.1 Study and comparison of Heliostat field design performance for beam up and beam down as mentioned accordingly	
	4.4.2 Comparison of optical efficiency and Stagnant temperature generation over four Heliostat sizes	
	4.4.3 Comparison between Hyperboloid and Ellipsoid field efficiency for the work as Beam Down was done for twelve chosen cases	
	4.4.4 Efficiency Comparison on the basis of Heliostats size	
Chapter 5 :	Temperature profile of the receiver: Detection at far-field using infrared detectors	139-149
	5.1 Estimation of receiver temperature	147
Chapter 6 :	Conclusions and future scope of work	150-153
	6.1 Duck Curve and Levelized Cost Of Electricity (LCOE)	152
	Appendix	155-169
	A.1 SolarPILOT	
	A.1.1 Design with SolarPILOT	
	A.2. SolTrace	
	A.3 SolarPILOT and SolTrace	
	A.3.1 TracePro, SolarPoilor and Soltrace : A comparative study	
	A.4 Angles for the purpose of rays to move from one point to the other	
	A.5 Mirror area (m ²) vs Land area (m ²) plot	
	A.6 Below is the grid source setup used for field design	
	A.7 Relevance and importance of curvature on the Heliostat	
	A.8 Excel script used in the thesis work	
	A.9 National and international selected work	
	A.10 Ray tracing work performed in this thesis	
	A.11 Beam down work with Non Imaging Optics (CPC)	
	A.12 Variety of field pattern designed	
	A.13 Validation of uncertainties in efficiency	
	A.14 Correction of Fig 4.13 regarding shadow area plot of Heliostat of measurement 5 x 5 : 25 m ² and 4 x 4 : 16 m ²	
	List of publications	170
	References	171- 179