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Review

Atmospheric extinction in solar tower plants – A review

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ABSTRACT

In solar tower plants, radiation losses between the heliostat field and the receiver occur due to atmospheric extinction which varies with site and time. Currently, atmospheric extinction is usually approximated using a few constant standard atmospheric conditions in ray-tracing and plant optimization tools. Some tools allow the input of time dependent extinction data, but such site specific data sets are generally not available for prospective concentrated solar power (CSP) sites. In this paper, the most applied model equations which are implemented in different ray-tracing tools are summarized and compared. Several developed approaches to determine atmospheric extinction are presented. Furthermore, different studies about the effect of atmospheric extinction on the tower plant yield are summarized. It can be concluded that project developers should consider atmospheric extinction and its temporal variation as site specific data sets in power plant optimization, plant yield forecast and plant operation. The effect of atmospheric extinction can account for a reduction of the annual plant yield of up to several percent points and is dependent on the heliostat field size, the operation strategy and the on-site atmospheric conditions. Different approaches to determine atmospheric extinction for solar tower plants at a future CSP site have been developed and validated in the past and can be applied dependent on the prevailing atmospheric conditions. The costs of a power plant can be lowered by reducing the simulation uncertainty since it implies in turn a reduction of risk margins in plant yield forecasts.

Contents

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Acronyms

ABC absorption and broadband correction
AERONET Aerosol Optical Network
AOD aerosol optical depth
bp barometric pressure
BLH boundary layer height
CESA1 tower facility at PSA
CSP concentrated solar power
DELSOL3 computer code of SANDIA for calculating the optical performance and optimal system design for solar thermal central receiver plants
DNI direct normal irradiance
DLR German Aerospace Center, Deutsches Zentrum für Luft- und Raumfahrt
ECMWF European Centre for Medium-Range Weather Forecasts
GREENIUS software tool developed by DLR
HELIOS Computer Program for Modeling the Optical Behavior of Reflecting Solar Concentrators
HFLCAL Heliostat Field Layout CALculation developed by DLR
HITRAN high-resolution transmission molecular absorption database
LOWTRAN2 Fortran computer program for atmospheric transmittance from 0.25 to 28.5 μm
LOWTRAN3 Fortran computer program for atmospheric transmittance from 0.25 to 28.5 μm
MENA Middle-East and Northern African
MIRVAL Monte Carlo program developed by SANDIA National Laboratories
MODTRAN MODerate resolution atmospheric TRANsmission computer code
MOR meteorological optical range
NREL National Renewable Energy Laboratory
OD optical depth
PSA Plataforma Solar de Almería
RH relative humidity
RMSE root mean square error
SAM System Advisor Model
SANDIA SANDIA National Laboratories
SoFiA simulation tool for Central Receiver Systems
SolTRACE ray-tracing Code for Complex Solar Optical Systems by NREL
SPRAY ray-tracing software developed by DLR
STRAL ray-tracing software developed by DLR
SVR standard visual range
$\mathbf{T}_{amb}$ ambient temperature
$\mathbf{T}_x$ transmittance per traveled distance x
$\mathbf{T}_{1km}$ transmittance for a slant range of 1 km
$\mathbf{T}_{600m}$ transmittance for a slant range of 600 m
$\mathbf{T}_{680m}$ transmittance for a slant range of 680 m
Tonatiuh open source, Monte-Carlo ray tracer
UAE United Arab Emirates
UTC Coordinated Universal Time
WinDELSOL1.0 DELSOL3 in a Windows environment
β_{ext} extinction coefficient

1. Introduction

Solar radiation in solar tower plants is attenuated between the heliostat field and the receiver due to atmospheric extinction. Atmospheric extinction is caused mainly by aerosol particles and water vapor which scatter and absorb solar radiation. This process is variable with site and time. Fig. 1 displays two exemplary situations at the CSP tower facility CESA1 at Plataforma Solar de Almería (PSA): one clear (left) and one rather hazy day (right). It can be seen that a part of the solar radiation is attenuated by the atmosphere dependent on the prevailing atmospheric condition.

To estimate the yield of a CSP plant, usually assumptions about atmospheric extinction are made and in most ray-tracing tools it is only possible to decide between a constant standard clear or a hazy atmospheric condition. Especially in arid environments, e.g. in the Middle-East and Northern African (MENA) region, which are of special interest for CSP due to the high solar radiation potential, this differentiation might not be sufficiently accurate. Recently,

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