STUDY ON FEASIBILITY OF USING CONCENTRATED SOLAR THERMAL BASED ELECTRICITY GENERATION IN SRI LANKA: CASE OF HAMBANTOTA

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Degree of Master of Engineering

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DECLARATION

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Prof. R.A Attalage

ABSTRACT

Based on the maturity, a suitable CSP technology was decided to start the concentrated solar thermal based electricity generation in Sri Lanka. Maturity was decided according to the quantities and capacities of plants around the world. 65 % of CSP projects in the world are used parabolic trough technology. 79 % of the total operational CSP plants are parabolic trough systems. 85 % of total operational capacity comes from parabolic trough. Therefore, parabolic trough technology is the most matured technology in CSP technologies. SAM 2017.1.17 version was used to analyze the parabolic trough CSP plant in Hambantota area. The analysis was performed for two cases. Case 1 was the analysis done for Hambantota solar data downloaded from SWERA library and the Case 2 was the actual solar data of Hambantota solar park obtained from SLSEA. 600 nos of combinations of PPA price, number of field subsections, solar multiple, and full load of TES (hr) were subjected to a parametric analysis. The best plant configuration at which the plant is feasible and the plant has minimum LCOE, is when the PPA price ($/ kWh), number of field subsections, solar multiple, and full load TES (hr) are respectively 0.5, 2, 6 and 16 for the Case 1. They are respectively 0.7, 2, 8, and 20 for the case with actual solar data. The estimated net capital cost per watt for the parameter set which gives the lowest LCOE of the Case 1 was 26.87 $/W. For the Case 2, it was 33.22 $/W. The annual energy generation of the Case 1 is 50 % higher than that of the Case 2.

Key words: Hambantota, Concentrated Solar Power, Levelized Cost of Energy, Solar Multiple, parabolic trough collectors

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TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF NOMENCLATURE

n	:	Julian day of year
δ	:	Declination angle
Γ	:	Day angle
$\emptyset$	:	Latitude
ω	:	Hour angle
θ_z	:	Zenith angle
α	:	Solar altitude angle
Az	:	Solar azimuth angle
θi	:	Incidence angle
β	:	Surface tilt angle from the horizontal
Azs	:	Surface azimuth angle
I_{SC}	:	Solar constant
I_{ON}	:	Extra-terrestrial radiation measured on a plane normal to the radiation
I_{OH}	:	Extra-terrestrial radiation measured on a plane parallel to the ground
λ	:	Wavelength
I	:	Total intensity of scattered unpolarized solar radiation incident on a molecule in the direction θ
I_0	:	Incident intensity
α	:	Polarizability of the molecule
r	:	Distance between the molecule and the point of observation
K_λ	:	Monochromatic extinction coefficient - assumed to be a constant for the medium
$I_\lambda(x)$	:	Monochromatic intensity after radiation has travelled a distance x
τ_λ	:	Monochromatic transmittance
I_N	:	Direct solar radiation
I_b	:	Beam radiation
I_d	:	Diffuse radiation
I_G	:	Global solar radiation
k	:	Optical depth
C_n	:	Clearness number
C	:	Sky diffuse factor

S : Daily sunshine hours

T : Daily average temperature

T_{min} : Daily minimum temperatures

T_{max} : Daily maximum temperatures

R_h : Daily average relative humidity

C_ω : Daily average cloud amount

$\bar{H}$: Monthly averaged daily radiation on the horizontal surface of terrestrial region

$\bar{H}_o$: Monthly averaged daily radiation on the horizontal surface of extra-terrestrial region

$\bar{S}$: Monthly averaged hours of sunshine

S_o : Monthly averaged maximum possible hours of sunshine

h_{ss} : Sunset hour

a : Site specific constant

b : Site specific constant

Af : Tropical forest climate, constantly moist, rainfall all through the year

Am : Tropical forest climate, monsoon rain, short dry season, bur total rainfall sufficient to support rain forest

Aw : Tropical forest climate, dry season in winter

BS : Steppe or semiaraid climate

BW : Dessert or arid climate

Cf : Mesothermal forest climate, constantly moist, rainfall all through the year

Df : Mesothermal snow forest climate, constantly moist, rainfall all through the year

Dw : Mesothermal snow forest climate, dry season in winter

N : Day number

$\bar{K}_T$: Monthly average clearness index

$\bar{H}_D$: Monthly average diffuse radiation on horizontal surface

$\bar{H}_B$: Monthly average beam radiation horizontal surface

H_t : Total insolation tilted flat surface

H_{Bt} : Direct insolation

H_{Dt} : Diffuse insolation

H_{Gt} : Ground reflected insolation

R_t : Solar radiation tilt factor

ρ_g : Ground albedo

H_{Bn} : Beam normal radiation component

H_B : Beam radiation component on a horizontal surface

R_B : Beam radiation tilt factor

ω_s : Sunset hour angle

ω_s' : Sunset hour angle at the tilted plane

H_R : Diffuse sky radiance

R_D : Diffuse solar radiation tilt factor

F' : Clearness index

A : Anisotropy index

H_r : Isotropic ground reflection radiance

C : Concentration ratio

A_a : Aperture area

A_r : Receiver area

R : Distance from the concentrator to sun

θs : Half angle subtended by the sun

Ts : Sun's temperature

$E_{r\text{-}s}$: Exchange factor

Tr : Receiver temperature

LIST OF ABBREVIATIONS

ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AST	:	Apparent Solar Time
CEB	:	Ceylon Electricity Board
CIF	:	Cost, Insurance and Freight
CSP	:	Concentrated/ Concentrating Solar Power
DNI	:	Direct Normal Irradiance
DSG	:	Direct Steam Generation
FOB	:	Freight on Board/ Free On Board
HCE	:	Solar Collector Elements
HTF	:	Heat Transfer Fluid
IEA	:	International Energy Agency
IRENA	:	International Renewable Energy Agency
ISCSS	:	Integrated Solar Combined Cycle System
ISES	:	Institute for Solar Energy Systems
LCOE	:	Levelized Cost of Energy
LFC	:	Linear Fresnel Collectors
LFR	:	Linear Fresnel Reflectors
LST	:	Local Standard Time
NEDO	:	New Energy and Industrial Technology Development Organization
NREL	:	National Renewable Energy Authority
O&M	:	Operation and Maintenance
PCM	:	Phase Change Material
PPA	:	Power Purchase Agreement
PS10	:	Planta Solar 10
PTC	:	Parabolic Trough Collectors
PV	:	Photovoltaic
SAM	:	System Advisor Model
SCA	:	Solar Collector Assembly
SCE	:	Solar Collector Elements

SEECOT	:	Solar Energy Enhanced Combustion Turbine
SEGC	:	Solar Energy Generating Systems
SERI	:	Sustainable Energy Research Institute
SHC	:	Solar Heating and Cooling
SLSEA	:	Sri Lanka Sustainable Energy Authority
SWERA	:	Solar and Wind Energy Resource Assessment
TES	:	Thermal Energy Storage
USA	:	United States of America