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Design, analysis and optimization of 50MWe solar thermal power plant in Multan using CSP Parabolic Trough technology.

Kamran Mahboob
Dept. of Mechanical Engineering
University of Engineering and Technology
Lahore / Chenab College of Engineering and Technology
Gujranwala, Pakistan
mahboobccet@gmail.com

Farman Ali
Department of Mechanical Engineering
Chenab College of Engineering and Technology
Gujranwala, Pakistan
farmanaliccet@gmail.com

Hassan Mehmood
Department of Mechanical Engineering
Chenab College of Engineering and Technology
Gujranwala, Pakistan
hassanccet@gmail.com

Muhammad Irfan
Department of Mechanical Engineering
Chenab College of Engineering & Technology
Gujranwala, Pakistan
m.irfanccet@gmail.com

Saqib Tanveer
Department of Mechanical Engineering
Chenab College of Engineering & Technology
Gujranwala, Pakistan
Saqib.ch946@gmail.com

Awais Khan
Dept. of Mechanical Engineering
University of Engineering and Technology
Lahore, Pakistan
awais211@uet.edu.pk

Abstract

Solar energy is the best and common way to produce clean renewable electricity generation now a days. Fossil fuels, air pollution, emission of greenhouse gasses affect our climate and cause different diseases. Solar thermal Power Plant is an effective and Eco-friendly system to produce electricity. Parabolic Trough technology is the advanced and commercially used power plant in the world. The southern region of Pakistan is receiving perfect amount of solar radiations comparable to one of the best in the world. These areas have suitable environment and optimistic potential for Concentrated Solar Power (CSP) and Photovoltaic (PV) energy productions. Southern region of Pakistan has appropriate and effective amount of solar radiation for our proposed project. Multan Punjab is situated in the same region of Pakistan with the highest value of DNI. The purpose of this paper is to design 50MWe Solar Power Plant using Parabolic Trough collector technology; it will be the first step towards clean energy production in Pakistan. This plant uses Therminol VP-1 as high temperature fluid. Storage tanks that can be used as energy storage are designed in that way; this plant is operative at night time and capable of producing electricity for 24 hours. The monthly and yearly production from proposed CSP power plant is found by performance analysis. It is revealed in this research that maximum energy production is achieved from March to October due to high solar radiation during these months. The minimum energy production is recorded in December and January. It is concluded that the efficiency of the Concentrated Solar Power (CSP) is greater than other renewable energy resources. It is recommended that Government should take interest in this type of projects as renewable energy CSP plant is pollution free process to produce electricity.

Keywords: energy; solar; renewable energy production; parabolic trough technology; CSP parabolic trough power plant.

1. INTRODUCTION

With the population and industrial growth of the world, energy needs are growing. This has forced the world to produce energy from fossil fuels in past century. One of the major drawbacks of fossil fuels is emission of green house gases. The quest for clean energy production has forced many industrial economies to shift from fossil fuels to renewable energy[1].

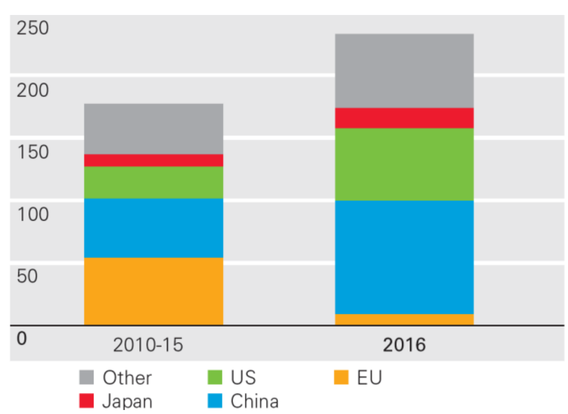

Fig. 1. Growth and diffusion of renewables [2]

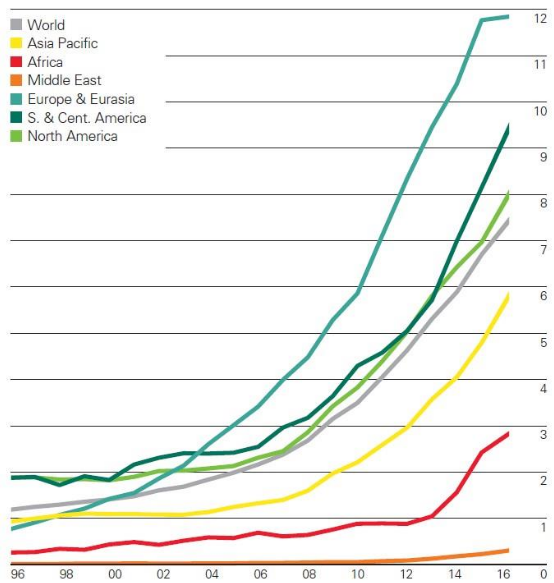

Fig. 2. Share of renewable (other than hydro) in power generation in different regions of the world [2].

Recent growth in renewable shows that world is shifting to renewable energy resources. There is a major shift in electricity generation and share of renewable has increased considerably. Europe and Eurasia region is leading in this regard and has the largest share.

Pakistan has followed the footsteps of developed countries and has greater dependencies on the fossil fuels currently. Nearly two third of the resources used in electricity generation is thermal. As major part of electricity generation and transportation [3] is using fossil fuels that is damaging the atmosphere severely. It has polluted the environment in all populated region severely. There is a dire need to shift a major portion of energy production from fossil fuels to renewable resources whose share is negligible [4].

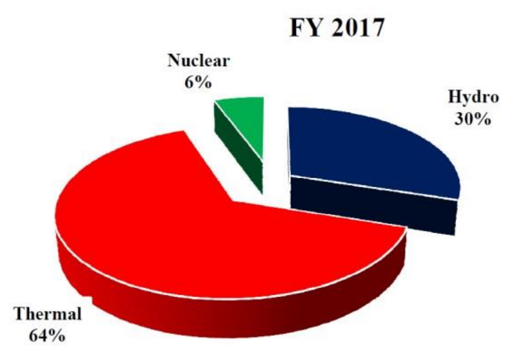

Fig. 3. Share in Electricity Generation FY2017, Pakistan [5].

2. SOLAR ENERGY

Solar energy can be used to harness energy from the sun into other forms of energies like thermal, electric etc. [6]. There are different ways to convert solar energy into electrical energy like PV panel, solar tower power plants, parabolic troughs, and parabolic dishes.

Pakistan is blessed with solar energy and has huge potential to harness this clean and free source of energy. By utilizing solar energy we can enhance power generation capacity and there will be little fossil fuel emission [7].

2.1. Global Horizontal Irradiance (GHI) for Pakistan

Nearly all regions of Pakistan and especially southern regions of the country are suitable for having greater solar radiations. More than 90% of the land has a GHI value greater than 1500 kWh/m^2 suitable for solar energy applications. It is estimated that annual mean GHI value of Pakistan is 2071kWh/m^2. It is clear from GHI value that Pakistan can be listed amongst countries which are rich in solar energy [8].

Southeren areas of Pakistan like Sindh, Balochistan, and Southern Punjab are best suited for CSP plant installation. These areas have around eight hour of daily sunshine and higher DNI values. Punjab is most populist region of Pakistan and has great demand of electricity. By installing a generation plant in southern Punjab can help in harnessing solar resources of the areas as well as reducing environment pollution.

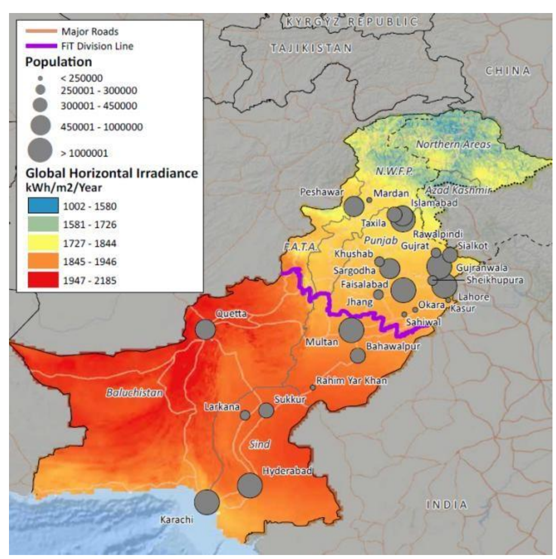

Fig. 4. Global horizontal irradiance of Pakistan [9].

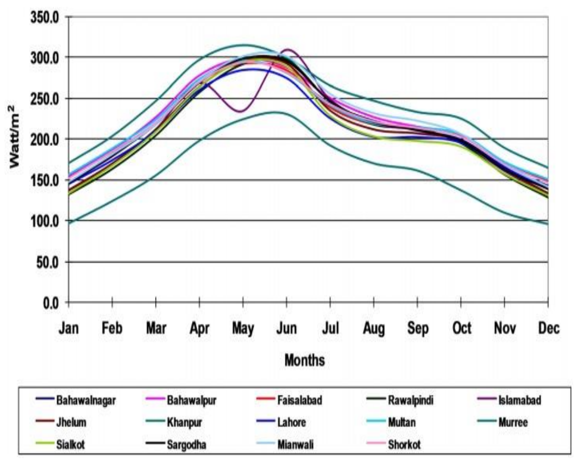

Fig. 5. Solar radiation in Punjab[10]

Solar radiation intensity greater than 200 W/m^2 is observed in most region of the Punjab from March to September. Multan lies in southern Punjab region and has high sunshine values therefore it is selected for CSP plant installation.

2.2. Parabolic Trough

PTC is a parabolic shape structure covered with mirrors or reflective film in one dimension, which reflects the rays coming from sun onto its focal line [11]. At its focal line there is a glass enclosed metallic tube receiver, which is coated with a high solar radiation absorber and low heat emission material. The receiver tube contains the heat transfer fluid, which is different for different applications. The Parabolic Trough Collectors are arranged parallel in the solar field to track the sun whole day [12].

Fig. 6. Sky Fuel Parabolic Trough collector [13].

3. 50MWe CSP plant design

The designing of PTC 50MW plant is initiated by selecting the suitable and appropriate site. Selection of site is a vital aspect for better production in any renewable energy project. The efficiency of the plant depends upon the DNI radiation intensity and solar field aperture area. For the initial designing of PTC plant the selected parameters are given as follows;

3.1. Collector Type

The collector preferred for the PTC plant is SkyFuel Trough. The characteristics of the SkyFuel Trough collector are given in Table 1. It is selected for the plant due to following features;

1) Low cost of the reflective film
2) Rigid and sustainable structure against severe climate
3) Better Thermal and optical efficiency
4) High torsion stiffness than Luz-1 and Luz-2 troughs.

Table. 1. Characteristics of the SkyFuel Trough (with 80-mm OD receiver).

Parameters	**Values**
Aperture Area	656 m^2
Total Structure Width	6 m
Collector Assembly Length	115 m
Modules Per Assembly	8
Single Module Length	14.375 m
Design Optical Efficiency	0.8484
Focal Length	2.15 m
Mirror Reflectance	0.93

3.2. Heat Transfer Fluid (HTF)

The HTF preferred for proposed PTC is Therminol VP-1 due to following characteristics;

1) Thermal stable operating temperature of the VP-1 ranges from 12 to 400℃.
2) Better thermal efficiency than other heat transfer fluid like Hitec Solar Salt etc.
3) Significant annual increase in energy production by using Therminol VP-1.

3.3. Receiver (Schott PTR80)

Another important aspect for better production in CSP plants is selection of receiver. Schott PTR80 is selected for the PTC plant. The characteristics of the Schott PTR80 receiver are listed in Table 2.

Table 2. All design parameters of the PTC plant

Parameters	Values
Total capacity of the PTC plant	50 MWe
Total covered land area	413 acres
Condenser Type	Air Cooled
HTF properties and Receiver	
Filed HTF fluid	Therminol VP-1
Design loop inlet Temp.	293℃
Design loop outlet Temp.	391℃
Pressure of Boiler	86 bar
Receiver Type	Schott PTR80
Inner Dia. of Absorber Tube	0.076 m
Outer Dia. of Absorber Tube	0.08 m
Glass envelope inner Dia.	0.115 m
Glass envelope outer Dia.	0.12 m
Absorber Material	304L
Solar and Collector Field	
Solar Multiple	2
Single loop aperture	5248 m^2
Row Spacing	15 m
Field Subsection	2
Total field reflector area	477568 m^2
Number of loops	91
Water usage per wash	0.7 L/m^2
Washes per year	63
Thermal Energy Storage	
Storage fluid	Therminol VP-1
Storage type	2 tanks
Thermal Storage (hr) (TES)	6 hr
Tank Diameter	20.1584 m
Thermal Capacity	943.82MWht
Tank loss coefficient	0.4 W/m^2-K
Storage tank heater efficiency	0.98
Estimated heat loss	0.4087MWt

4. Performance Analysis of PTC plant

The performance analysis is done by analyzing the monthly energy generation from the PTC plant in Multan, Pakistan. Annual energy generation of the proposed PTC plant is obtained 90,484,504 KWh.

Maximum monthly energy generation from March to October varies from 10.28 GWh to 6.718 GWh. The energy production during July is pointedly low due to the rainy season in Multan. From November to February minimum energy production received from PTC plant varies from 3.953 GWh in December and 3.47 GWh in January.

Fig. 8 illustrates the data of field thermal power incident, cycle thermal power output and cycle electric power output.

The values of these cycles depend upon the intensity of solar radiations in the region selected for the proposed PTC plant. The maximum and minimum values recorded for the thermal power incident are 315.7064 MW and 197.239 MW in March and December respectively. 59.8192 MW is the highest value of the electric power output received from March to October.

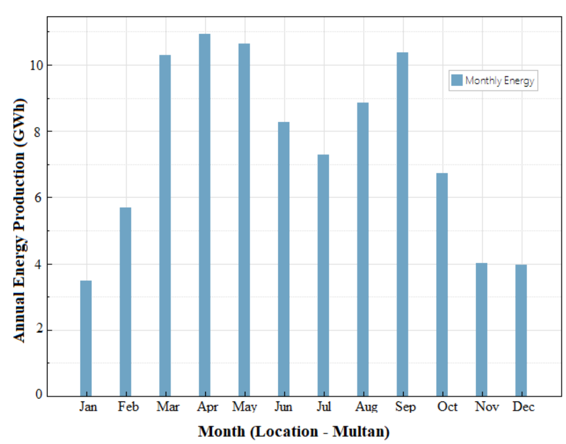

Fig. 7. Monthly energy generation from PTC in Multan.

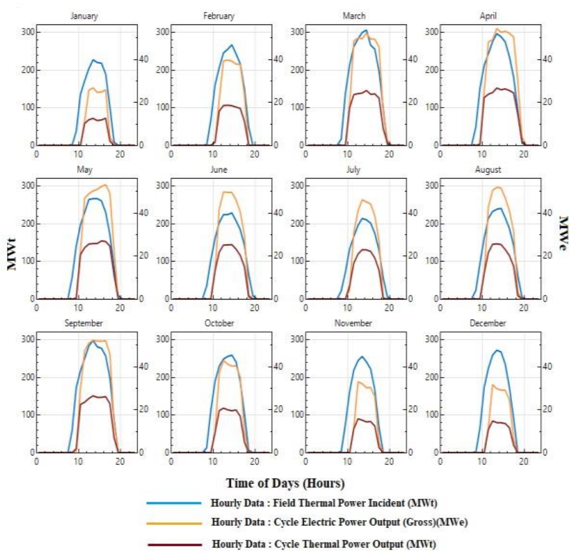

Fig. 8. Plot of Thermal power incident, cycle electric power output and cycle thermal power output

The mean efficiency (Gross) 0.1088 and maximum efficiency 0.393 are recorded for the proposed PTC plant as shown in Fig. 9.

Annual energy production for the proposed CSP Parabolic trough plant is find out 90,484,504 KWh with a capacity factor of 20.5%. The gross to net recorded efficiency of the plant is 88.8%.The detailed information after simulation of the plant is shown in Table.3.

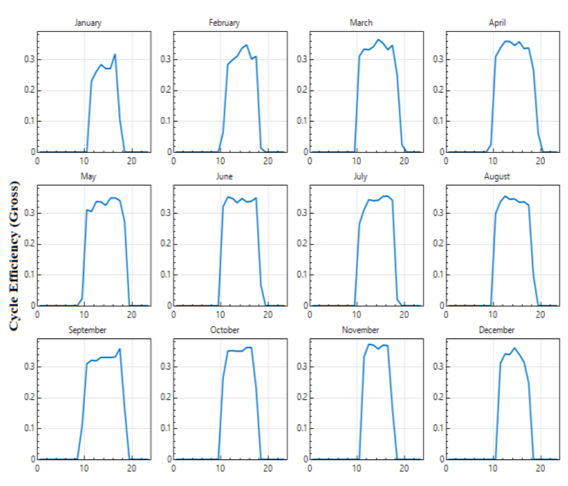

Fig. 9. Cycle Efficiency (Gross)

Table.3. Annual energy production for PTC plant.

Characteristics	Values
Annual energy production	90.48 GWh
Capacity Factor	20.5%
Gross to net efficiency	88.8%

5. Results after optimization

Optimization of the initial design of Parabolic trough plant is performed by changing the values of solar multiple and thermal storage (TES) (Fig. 10 and 11) and the results are illustrated for varying solar multiple and thermal storage (TES).

From Fig. 10 it is clear that by increasing solar multiple, the annual energy production will increase. Actually, by increasing solar multiple, we directly increase the reflective aperture area of solar filed.

It is observed that, there is a significant change appeared in annual energy production by changing the values of solar multiple. The solar multiple selected for the initial designing of proposed PTC plant with a corresponding energy generation is 90.4 GWh is 2. If we increase the value from 2 of solar multiple, a substantial change will occur. The optimum value of solar multiple for the PTC plant is around 8 for better energy generation.

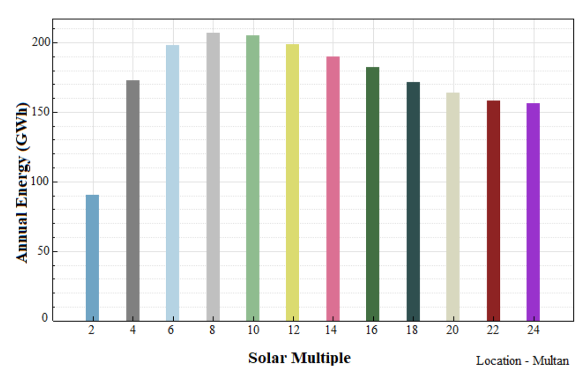

Fig. 10. Variation of solar multiple with annual energy production for PTC plant in Multan

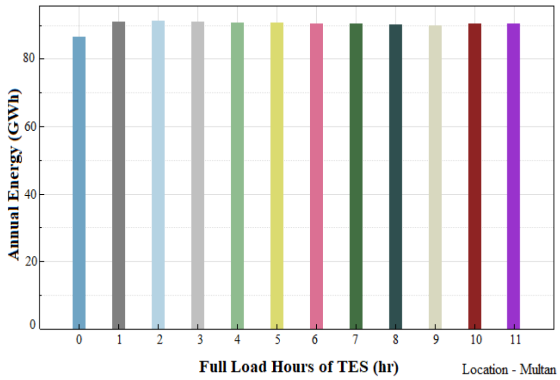

Fig. 11. Variation of thermal storage (TES) with annual energy production for PTC plant in Multan

Another constraint of optimization is thermal energy storage (TES), which provides energy during the period of low radiation or in night time to the power block to produce electricity. Moreover, the main reason of using thermal storage in the plant is to avoid energy generation breakdown.

Fig. 11 shows the variation of thermal energy storage (TES) with annual energy production. The thermal energy storage time for the selected plant is 6 hours, corresponding annual energy production is 90.4 GWh. Increase in the storage time simply means the increment of investment in the plant and reduction in the annual energy production. The optimum value of TES for the proposed plant is 2 hours with energy generation of 101.64 GWh. Energy generation can be increased by increasing the thermal energy storage of the plant within certain condition.

6. Final result summary

The optimization simulation has revealed improvement in net energy generation. A comparison between initial designing and optimize final result is shown in Table 4.

Table.4. Comparison between initial and optimized designing of PTC

Parameters	Multan, Punjab Pakistan	
	Initial	Optimized
Annual Energy GWh	90.48	101.64
Capacity Factor	20.5 %	23 %
Solar multiple	2	2.2
Load hours	6 hrs.	2 hrs.
Gross to net efficiency	88.8%	89.8 %

7. Conclusions

It is evident from survey of the location that southern Punjab region is suited for solar energy production. The optimized result has shown that 101.64 GWh of energy is produced with storage load hours of 2 hrs. It is evident that increase in solar multiple will increase the production and maximum generation can be achieved at point where solar multiple is 8. Design and optimization has shown that Multan has good potential for solar energy production and also this area is suitable for CSP plant installation.

Punjab is most populated region and Multan is one amongst the mega cities of Pakistan. A Clean and green house free plant in this region will overcome energy demand with no emission. This will help in reducing the pollution.

Special subsidies from Govt. are requested in this regard. It will also helpful in human and capital development of the country. A designing, fabrication and installation will create new jobs.

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NOMENCLATURE

CSP	Concentrated Solar Power
PV	Photovoltaic
DNI	Direct Normal Irradiance [KWh/m^2]
GHI	Global Horizontal Irradiance [KWh/m^2]
HTF	Heat Transfer Fluid
PTC	Parabolic Trough Collector
TES	Thermal Energy Storage
η_{Eo}	Mean efficiency

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