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DESIGN AND ANALYSIS OF 50MWE SOLAR POWER PLANT IN MULTAN USING SOLAR POWER TOWER TECHNOLOGY

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Abstract

Energy is basic need of the world and its growing demand shows that producing energy is one of the major challenges in the world. Pakistan is suffering from the severe energy crisis and indigenous resources are quite limited to produce electricity. The renewable energy resources enable us to produce electricity that is clean and plays an important role in decreasing greenhouse gas emissions. Pakistan lies in an area of one of the highest solar radiations and DNI at some regions is comparable to some of the best in the world. Southern Punjab lies in this area and is suitable for solar thermal power projects that's why Multan is selected to design a solar concentrated tower power plant. The purpose of this paper is to show the detailed analysis procedure of the first concentrated solar tower power system. The design of concentrated solar tower power plant is 50 MWe. The system design consists of heliostats directing incident solar rays to the top of tower. The rotational and elevation movements of each heliostat are controlled by motors. A solar receiver made of stainless steel AISI 316 is installed at the top of the tower to get solar radiations reflected from the heliostats. A molten salt fluid consists of 60% sodium nitrates (NANO3) and 40% potassium nitrates (KNO3) circulated in the receiver. This plant can produce electricity for 24 hours as compared to others because of thermal energy storage that runs the plant even at night time. The monthly and yearly electricity production of the plant is predicted in this research. It is presented that which months are producing maximum and minimum energy. Recommendations are given to the government to install this type of projects which are environment friendly.

Keywords: Renewable energy; Environment; Concentrating solar energy; Solar tower power plant; Molten salt HTF.

1. INTRODUCTION

The issue of global warming, carbon and green house gases emission that is produced by the fossil fuel power plants is a major issue in modern day world. To overcome this problem solar technologies are used in many countries. There are various methods used to generate electricity by harnessing the solar energy. Concentrating solar-power (CSP) plants is one of these techniques and these plants are installed to produce electricity in many countries in the world. Concentrating solar-power (CSP) technologies, as well as power towers, solar cell, parabolic troughs have the possible way to give the world with renewable, clean and cheap energy in the upcoming years [1]. Solar-power tower plants shows up by way of having significant and high-efficient potential. Solar power tower plants operate by directing sun rays from a collection of thousands of mirrors called heliostats on to a solar receiver placed on the top of a tower [2]. Heat transfer fluid is used in the receiver to absorb heat and then it is transferred for electricity production. Some plants use superheated steam that is produced directly in the receiver to run steam turbine. But other uses molten salt as a heat transfer fluid which presents the most profitable methods and it is best HTF in this technology [3]. For past 10 to 20 years a number of experimental or economic systems have been built on SPT plants.

2. DNI in Pakistan

It is estimated via Satellite data that nearly 75% of Pakistan's land area has 2000 kWh/m² annual average GHI and 92,6% has 1500 kWh/m² [4]. In Pakistan, for ten hours in a day, normal solar radiation intensity lies between 1500W/m^2/day to 2750W/m^2/day, specifically in southern Punjab, Balochistan and Sindh areas throughout the year. Solar radiation intensity values greater than 200W/m^2 are observed in Sindh from February to October. In Balochistan approximately all areas from March to October are above than 200W/m^2. In KPK, Gilgit Baltistan and Kashmir regions, solar radiation intensity is above than 200W/m^2 from April to September. In Punjab regions radiation intensity is greater than 200W/m^2 from March to October.

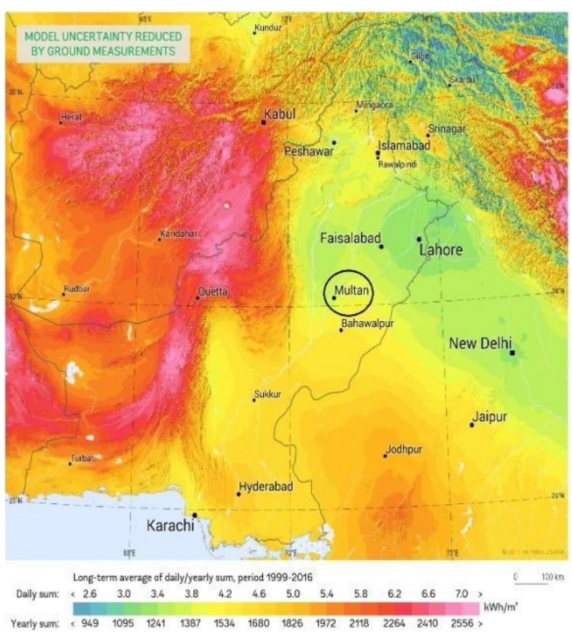

Fig. 1. Direct normal irradiance map of Pakistan [5]

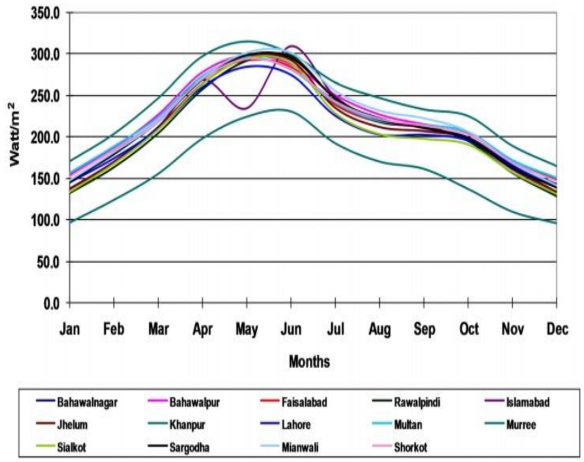

Fig. 2. Solar radiation in Punjab [6]

2.1. DNI in Punjab Regions

In Punjab region, we can get good range of direct normal Irradiance but it varies from north to south. The lowest solar radiation intensity measured in sticky region of northeastern Punjab in month of December is 96.11W/m^2 while the maximum intensity at southern region of Punjab in month of May is 315.14W/m^2. Solar radiation intensity was observed more than 150W/m^2 in upper region of Punjab except Murree. In lower southern area of the Punjab like Bahawalpur and Bahawalnagar, we can get extreme potential throughout the year. In most central and lower region of Punjab, radiation intensity is observed greater than 200W/m^2 between the months of March and September, like Sialkot, Mianwali, Lahore, Faisalabad, Multan and others. Average monthly solar radiation of Punjab lies in 138.73W/m^2 to 286.81W/m^2 range throughout the year [6].

2.2. DNI in Multan

In Southern Punjab region, we can get good range of direct normal Irradiance. In Southern Punjab approximately all areas from March to October have Solar radiation intensity values greater than 200W/m^2. Multan lies in this region and is suitable for installation of solar thermal power plant.. Fig. 3 shows a plot of global and horizontal irradiance in Multan. Global horizontal irradiance is nearly 900 W/m^2 from April to September.

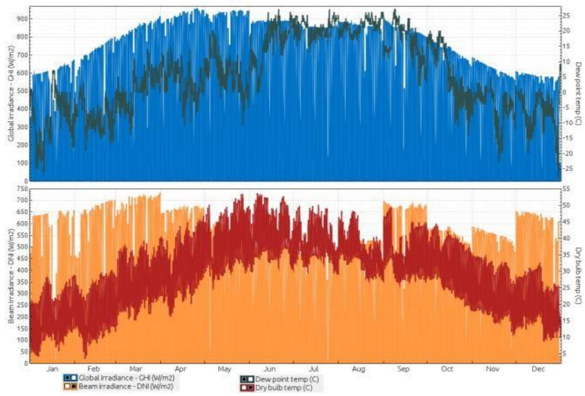

Fig. 3. Global and beam irradiance of Multan

3. Solar Power Tower and its Components

In solar power tower plants solar rays are focused to a focal point and that concentrated light is then converted to heat and then electrical energy.

3.1. Heliostat

Heliostats are main parts of solar tower system. It tracks the motion of sun and reflects the rays of sunlight continuously to make sun rays focus on the top of the tower [7]. Thousands of mirrors are installed around the tower. Axes tracked mirrors are totally computer controlled. If sunlight is fully focused on the top of the tower then this system is very accurate. Heliostats have fine reflectivity, much accurate tracking system and resistance to force exerted by wind [8].

3.2. Tower

In solar tower power plant, tower is used to mount the receiver on the top. It is either a steel structure or made of concrete.

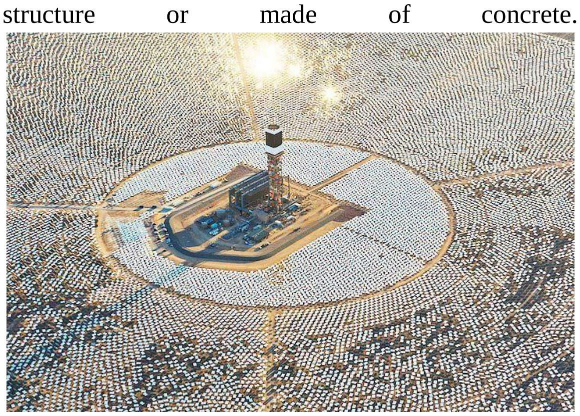

Fig. 4. Ivanpah solar tower power plant [9]

Height is the main design parameter of tower and it depends upon Capacity of plant and area of heliostat field.

3.3. Receiver

Performance of the plant mainly depends on the receiver. It is the main part of solar tower system. Its purpose is to absorb solar radiations reflecting from heliostats and convert it into heat which will use to generate steam and operate turbine [10]. Efficiency of solar tower system is mainly related to the receiver. Receiver is made up with different materials according to their properties. Receiver has two types which are External and Cavity receiver. External receivers have no cover or packing around it due to that it's output is less because of loss of heat due to convection while cavity have proper tubes welded with it for reducing the heat losses due to convection. Cavity receiver may be of single or dual cavity type which will have solar field on one or both sides

3.4. Heat Transfer Fluid

In the system HTF is used with a specific amount required to run the process. It is important element in solar power tower system because of its working phenomena. Without HTF there will be no production. Heat transfer fluid like molten salt [11] or hot air is used to transfer heat from receiver to a steam generator of steam turbine which produces superheated steam. It should be selected according to its thermal properties. It should be cheap and harmless. The selected HTF depends upon characteristics of piping and storing ability. Mostly used HTF are Water, Molten Salt, Air and Direct Steam

3.5. Power Cycle

Power block is also an important element of solar tower power plant in which solar energy collected by receiver is converted into electrical energy. In solar power tower plants two main power cycles are used which are Rankine Cycle and Bryton Cycle.

In Rankine cycle heat transfer fluid is water. Here we raise the temperature of water and convert it into steam. These saturated dry vapors sticks on turbine blades for generating power. After passing through turbine, at low pressure, that low quality steam passes through the condenser where vapors again converted to water. After that, it pumped from lower pressure to higher pressure and remaining constant pressure heat is taken by sub cooled water which transfer into steam and that cycle goes on again and again.

3.6. Thermal Energy Storage:

TES is known as heat storage of solar thermal power system. It energizes the system to run even when there is no sun light, like night or bad weather. This technology is mainly used to store extra heat during day by heating HTF and save the HTF in insulated containers. Simply this phenomenon increases the production of the plant [12].

4. MODELING AND SIMULATION

Modeling process start with selecting the weather data for the location selected. Preliminary design variables are selected for 50MW solar thermal power plant. Detail of different components is as follows,

4.1. Heliostat design

Design parameters of heliostat are included in Table 1. A total of 27977 heliostats are placed around the receiver.

Table 1: Heliostat Parameters

No	Variable	Value	Unit
1	No of heliostats	27977	
2	Reflectivity	0.97	
3	Direct Normal Irradiance	733	W/ m^2
4	Wind stow Speed	15	m/s
5	Heliostat deploy angle	8	Degree

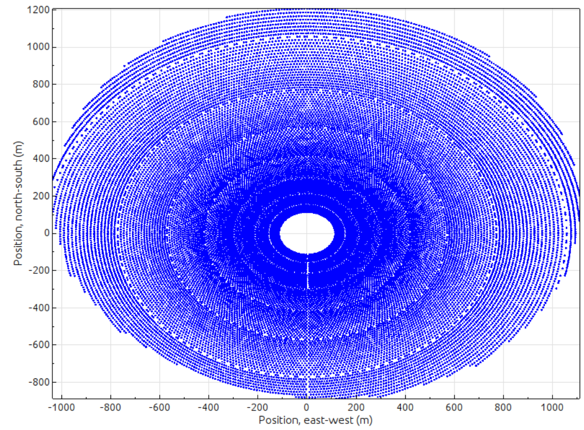

Fig 5: Heliostat Positioning

Simulations are carried out and pattern of heliostat placement around the tower is plotted. Optimization of the field is carried out to get the maximum output of the plant. Heliostat positioning is shown in Fig. 5.

4.2. Receiver & Tower Measurements

The sunlight rays reflected from heliostat and focused onto the receiver which absorbs heat and that heat will further use to generate electricity. As tower and receiver are main parts so there's arrangement and positions also matter a lot. Based upon heliostat numbers and position tower height, receiver height and receiver diameter are optimized. Details of receiver and tower parameters obtained from the simulation are enlisted in Table 2. .

Table 2. Receiver &Tower Parameters

No	Variable	Value	Unit
1	Receiver height	13.3695	m
2	Receiver diameter	10	m
3	Tower height	152.921	m

4.3. System Design

Table 3. System Design Variables

No	Variable	Value	Unit
1	Gross Output	55	MWe
2	Conversion factor	0.9	
3	Net Output	49.5	MWe
4	Thermal efficiency	0.4	
5	Thermal Power	137.5	MWt
6	HTF hot temperature	574	℃
7	HTF cold temperature	290	℃

4.4. Properties of Molten Salt

Molten salt is used for designing the power plant. Molten salt (60% sodium nitrates (NANO3) and 40% potassium nitrates (KNO3)) is used as heat transfer fluid. It is used because we are also establishing a thermal storage that will run the plant during non solar hours. Properties of heat transfer fluid are enlisted in Table 4..

Table 4. Properties of Molten Salt $NaNO_3$-KNO_3 (60-40%) solution

No	Variable	Value	Unit
1	Heat capacity at 300^0C	1495	J/kg.K
2	Melting Point	220	^0C
3	Thermal Stability limit	600	^0C
4	Thermal conductivity	0.55at 400^0C	W/m.K
5	Viscosity at 300^0C	1899	Pa.s
6	Density at 300^0C	.00326	Kg/m^3

4.5. Thermal Storage

At the plant use thermal storage for avoiding from solar requirements and provide the energy requirements when needed. The benefit of this power plant is to store the energy for 24 hours production due to its thermal storage process. Molten salt is used as a heat storage media. TES system certifies that the power block gets more energy when there is no solar radiation with the capacity of its 5 hours of storage system.

Table 5. TES Characteristics

No	Variable	Value	Unit
1	Type of storage	Two tanks	
2	Fluid of storage	$NaNO_3$-KNO_3	
3	Storage tank volume	3427	m^3
4	FLHOS at PC	05	Hours
5	Diameter of tank	17.1	M
6	Wetted loss-coefficient	0.4	W/m^2-K
7	Estimated heat loss	0.28	MWt
8	Heater Efficiency	0.99	

5. RESULTS

Fig. 6 demonstrates the hourly data of incident field thermal power, PC electrical output (gross) and PC thermal input for the selected plant in Multan. PC electrical output (gross) from plant depends on the incident irradiation and PC thermal input to turbine. Maximum value of incident field thermal power is found to be 497.3MWt. Maximum value for PC thermal input is found to be 143.2757MWt.

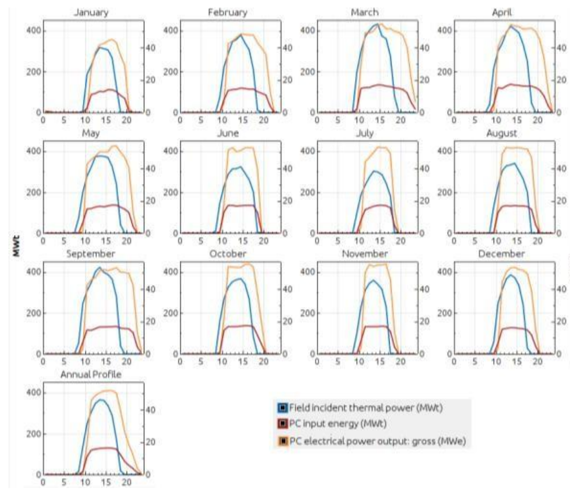

Fig. 6. Hourly data of PC thermal input, PC gross electrical output and Incident field thermal power for the plant

Fig. 7 demonstrates the efficiency of the cycle of selected SPT plant in Multan. The maximum value of cycle efficiency is 0.4293 recorded.

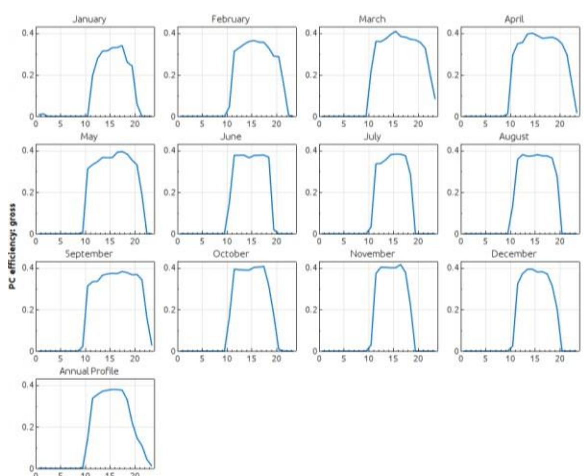

Fig. 7. PC efficiency of the Power Plant

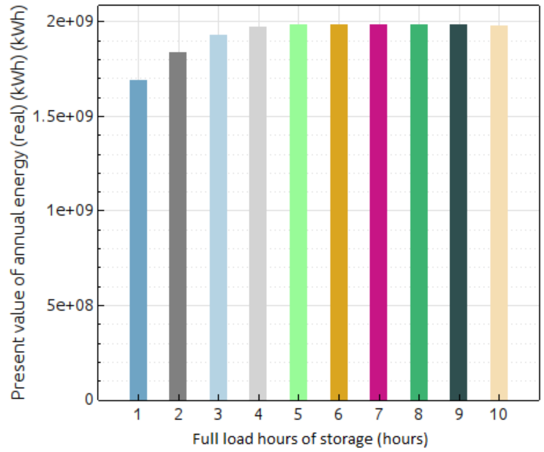

Fig 8: Variation of TES hours with Annual Energy

The annual energy production from the plant is 148,031,488 kWh with capacity factor of 34.1%. Fig. 8 shows present value of annual energy is plotted against Full load hour of the storage. The optimal value of TES hours for SPT ranges between 5 and 6. The optimal value of TES for the plant in Multan is 5hours is selected.

Solar multiple is the ratio of power cycle capacity to solar field capacity. If increase the solar multiple, aperture area also increases and the annual production from the plant also increases. Fig. 9 shows a plot of present value of annual energy against solar multiple. Increasing solar multiple increases annual production till 1.5 and then it is decreased gradually. The optimal value of Solar Multiple lies between 1.5 and 2 for solar power tower in Multan.

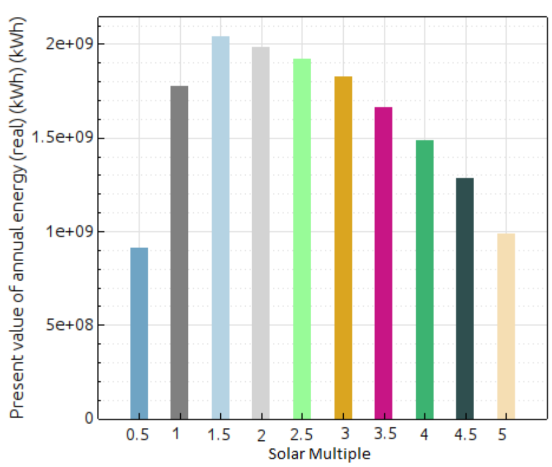

Fig 9: Variation of Solar Multiple with Annual Energy

6. CONCLUSIONS

It is evident from this research that Pakistan is rich in solar energy resources. Southern part of the country has great potential to become solar energy hub in future. The result of the initial analysis revealed that the annual energy production from the plant is 148 GWh with the capacity factor of 34.1%. The optimize value of Solar multiple is 1.5 to 2 and for of TES is 5 hours of the selected Solar Power Tower Plant in Multan,. Based on research, it demonstrates that Multan site is ideal for setting up of 50 MWe Solar power Tower Plant. The selected Multan region is feasible for energy production.

Most of new plants installed in Punjab are fossil fuel plants. So it will be a great step towards clean energy production. This will reduce the pollution and green house emission near to the populated Punjab region. And, by installing the CSP Plant in this site could contribute attractive amount of energy for future of this region and can overcome the dependency on fossil fuel.

It is recommended that special subsidies should be given by the government during design, development and installation of solar power plant. Moreover land should be given on lease so that it will make possible to erect the plant so that energy needs of the country should meet..

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NOMENCLATURE

CSP	Concentrated Solar Power
SM	Solar Multiple
DNI	Direct Normal Irradiance
HTF	Heat Transfer Fluid
SPT	Solar Power Tower
TES	Thermal Energy Storage
PC	Power Cycle
FLHOS	Full Load Hours of Storage

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