An Overview on Application of Solar Thermal Power Generation

Vedant Vyas, Dilip Jani

Abstract— Due to worldwide population growth and industrialization, the need of energy is growing rapidly. The conventional energy resources like coal, gas, oil are depleting day by day and will finish soon. To accommodate this need of energy, renewable energy resources will play a crucial role. One of them most promising energy resource is solar energy. This paper reviews the different technologies of solar thermal power generation such as parabolic trough, Linear Fresnel, Central receiver and parabolic dish. From all the technologies of solar power generation, parabolic trough technology is found to be most suitable for solar thermal power generation. A review on energetic and exergetic efficiencies is also carried for different sub assemblies of solar thermal power plant.

Keywords — Exergy analysis, renewable energy, solar energy, solar thermal power plant

I. INTRODUCTION

Owing to increase in population and living standards of people, the demand of energy is increased drastically. The present sources of energy such as coal, oil, fossil fuels are depleting day by day and in future, it will be finish. Hence, a growing need for renewable energy has been emerged to compensate the absence of non renewable energy resources in future. Due to conventional resources, the environment pollution becomes a major problem. It is thus required to reduce the use of conventional energy resources. The renewable energy is green energy and available in all over the world.

A country like India, there is enormous land available with plenty of solar irradiation. Such regions can be utilized by promoting solar energy as an alternative source to accommodate high energy demand. Solar thermal system uses solar energy and by utilizing it, steam can be generate to meet the power generation demand. It uses a set of solar collectors that transforms solar radiation energy into internal energy of working fluid such as air or water. Such collected energy is then used for power generation. Solar thermal system can be of stationary or with sun tracking system.

Present study analyze the opportunity, potential and challenges of renewable energy resources for existing thermal power generation condition based on gross assessment of available renewable energy resources. This paper summarized the techniques which is helpful for conversion of solar energy to produce useful energy with their energy-exergy analysis which makes the paper useful for researcher who works on efficient utilization of solar energy as well as to the industrial solar project beginners.

II. OVERVIEW ON SOLAR THERMAL POWER GENERATION

A simulation of line focus parabolic trough solar collector is carried out by Bakos et al. [1]. The result shows that the collector efficiency as a function of HTF flux, pipe diameter, solar radiation intensity and active area of PTC. The efficiency can be improved by increasing HTF flux. You and Hu [2] has investigated the efficiency optimization of a medium temperature solar thermal power plant. They found that the reheat-regenerative rankine cycle is a most appropriate cycle for parabolic trough collector. Also, higher the temperature of fluid entering the collector, lower the efficiency of collector. The exit temperature of fluid is at maximum temperature that the collector can operate to take most advantage of collector. An analysis of wind flow and heat transfer in receiver tube around parabolic collector is investigated by Naeeni and Yaghoubi [3] by considering effect of collector's angle of attack, wind velocity and its distribution with respect to height from the ground. A simulation of designed plant for Jordanian climate is carried out by Badran and Eck [4]. They evaluated the application of parabolic trough technology and provided the best suitable location for parabolic trough power plant. An analysis of design of solar boiler is conducted by Munoz et al. [5]. They found that the overall efficiency of conversion from direct solar irradiation energy to electricity is about 20%. Montes et al. [6] investigated the performance of 500MW parabolic trough power plant with direct steam generation and thermal energy storage with auxiliary gas fired boiler. They found that the annual performance parameters and size of thermal storage is a function of solar multiple. It is also found that the unit cost is high for greater value of solar multiple owing to the fact of greater investment cost in solar field. The annual fuel consumption is reduced as solar multiple increases mainly due to the thermal power fraction from the solar field and storage become greater. A thermodynamic model to estimate the backup fraction needed in 100MW hybrid solar fossil parabolic trough power plant is developed by Larrain et al. [7]. The most appropriate location is selected in northern Chile based on minimum fossil fuel backup. The model considers the collector's utilizability by estimating the heat losses in the absorber element and computing critical radiation parameters. The energy need to add during the cycle of operation is a function of radiation levels and collector performance. Kalogirou [8] did research to select best system

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for solar thermal power generation in Cyprus. They conclude that in view of cost of electricity, central receiver system and to exploit plant in steps, parabolic dish type system is useful. Parabolic trough and central receiver is used to obtain superheated steam which is then used to drive turbines of common rankine or of integrated combined cycle. Srinivas and Reddy [9] investigated solar parabolic collectors to produce steam for power generation. They found that with increase in solar radiation from 10% to 50%, the plant energy efficiency also increases from 16% to 29% at boiler pressure 20 bar. By considering locations of India, Sharma et al. [10] evaluated the optimal combinations of designed DNI, solar multiple, and storage hours for least cost of parabolic trough thermal power plant. They concluded that the cost is minimum for designed DNI range of 600-650 W/m^2 with range of solar multiple of 1.5-1.6. results also shows that for plant without storage, the electricity output in plant with storage is more but the cost of electricity delivered is increases. Rohankar et al. [11] summarized the scenario of solar power project in India. The issues for solar power in India are also taken in to account.

III. WORLD SOLAR ENERGY SCENARIO

Solar energy is the energy which is available all over the world. Fig 1 shows the available solar irradiation across the globe. The countries which are above latitude 45^0 N or below latitude 45^0 S, the annual average solar irradiation flux is of 1.6 MW h/m^2. Some region like Sahara desert, Mojave desert and some region of middle east are the hottest region and receiving plenty of solar irradiation. [12].

There are some countries which have implemented the solar thermal power plant technology like Spain, Germany, India etc. Here table 1 shows the installed plant location with its capacity, thermal energy storage hours and land required for setting up the solar thermal power plant.

Table 1 Various solar thermal power plant across the globe [13].

Plant name	Country	Capacity (MW)	Storage (h)	Land (ha)
PS 10	Spain	10	1	55
Julich	Germany	1.5	1.5	8
ACME	India	2.5	0	4.8
Dahan	China	1.5	1	5.2
Ivanpah solar tower	US	392	0	1417

IV. INDIA'S SOLAR ENERGY POTENTIAL

India is one of the largest consumer s of energy in the world and most of the energy for use is based on fossil fuels which is depleting day by day. To overcome the growing need of energy, the renewable energy resources are the best solution for country like India. India, with plenty land, is getting abundant solar irradiations of 200 MW/Km^2 with 250-325 sunny days over a year. The solar energy is distributed in every part of India but Rajasthan, Gujarat and north-west India is receiving highest part of it. [14].

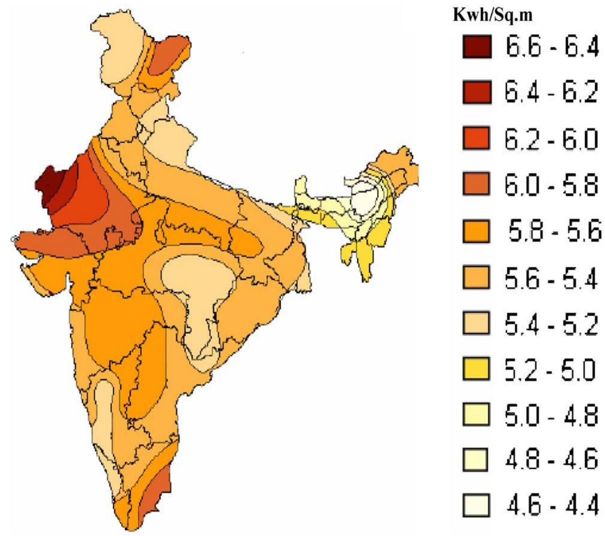

Fig 1 Solar radiation on India [15]

India has also launched Javaharlal Nehru National Solar Mission (JNNSM) to accommodate the need of energy in 2010. A target to obtain 20,000 MW of solar energy in 2022 is set. India's current electricity generation capacity is 135401.63 MW [16]. The state wise electricity generation capacity is given in table 2.

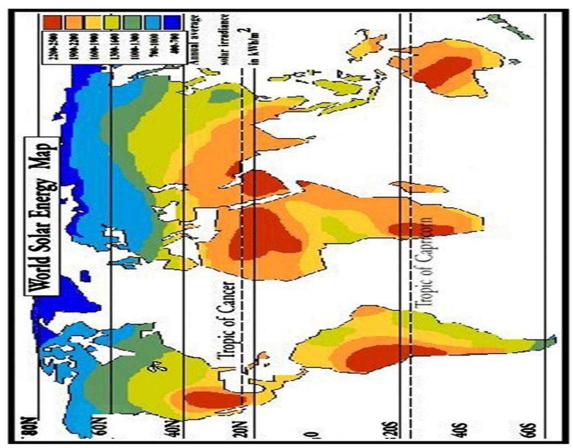

Fig 2 World solar energy map [12]

Table 2 State wise solar energy production

State	Solar power project (MW)
Andhra Pradesh	247.60
Gujarat	1000.05
Karnataka	78.22
Maharashtra	363.70
Orissa	31.92
Punjab	195.27
Rajasthan	1047.10
Uttar Pradesh	71.26
Tamil Nadu	147.68
Telangana	62.75
Madhya Pradesh	563.58

An overview of India's power sector is shown in fig 3. It can be seen that the largest amount from which energy is obtained is thermal resources (67.8%) like coal (58.3%), gas (9%) and oil (0.5%). The share of renewable energy is of 12.3%. the other power generation techniques are also shown in figure 3.

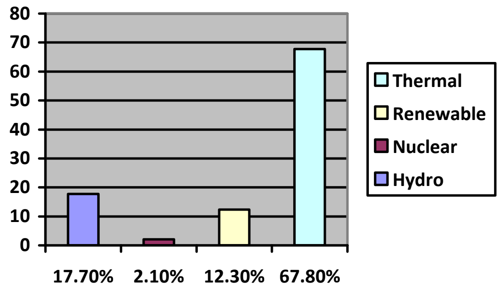

Fig 3 Overview of Indian power sectors [17]

V. SOLAR THERMAL POWER TECHNOLOGIES

Depending on the type of receiver, the CSP technology can be classified in two types : Fixed receiver and mobile receiver. In fixed receiver, the receivers are stationary which are independent of plant's focusing devices. In this case, it is very convenient to transport the collected heat to the power block. In mobile receiver type, receiver moves with focusing device. Because of that reason, mobile receiver collects more energy. According to the focus type, the technology can be of line or point focus type. PTC and LFR technologies are line focusing systems which focuses the solar irradiation on receiver typically oriented in north-south direction whereas CRS and PD technologies which focuses the solar irradiation according to the location of receiver at a point. [18].

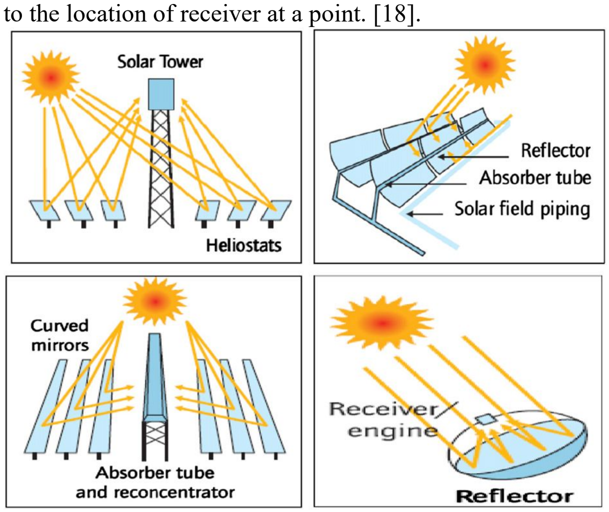

Fig 4 (a) STP (b) PTC (c) LFR (d) PDC [19].

The currently available solar thermal power generation technologies are:

1) *Parabolic Trough Collector (PTC)*
2) *Linear Fresnal Reflector (LFR)*
3) *Solar Power Tower (SPT)*
4) *Parabolic Dish (PD)*

The comparison between these technologies is illustrated in table 3. The various cycle of operation, their respective temperature, efficiency are listed in table 3.

Table 3 comparision among different solar thermal systems [17, 19, 20, 21]

Characteristic	PTC	SPT	LFR	PD
Power (MW)	30-300	100-200	1-100	5-25
Operation temperature (^{0}C)	300-400	585	150-500	800
Focus type	Linear	Point	Linear	Point
Optical concentration ratio	28:1	100:1-maximum	8-1	50:1
Peak efficiency (%)	20	19-23	10	29.4
Land requirement (m^2/MW)	40,000	83,600	18,000	16,000
Relative cost	Low	High	Very low	Very high
Cooling water (L/MWh)	3,000 or dry	1,500 or dry	3,000 or dry	None

VI. EXERGY ANALYSIS FOR DIFFERENT SOLAR THERMAL POWER TECHNOLOGIES

Singh et al. [22] carried out an exergetic analysis of solar thermal power system by using parabolic trough collector system and found that the main energy loss takes place at condenser (72.37%) of heat exchanger but losses are maximum at collector-receiver assembly (56.15%). The reason behind this is at the collector-receiver assembly, high quality of energy is lost but energy lost in heat exchanger part is of low quality. Analysis is considered to evaluate energy to run a thermodynamic rankine heat engine cycle for power generation.

Reddy et al. [23] investigated exergetic analysis of 50 MW plant to evaluate the performance of parabolic trough concentrating solar thermal power plant. The operating pressure of rankine heat exchanger is optimized for maximum efficiency and found that the energetic and exergetic efficiencies can be increased by 1.49% abd 1.51% respectively with increase in pressure of 90 bar to 105 bar. The variation of load of solar thermal power plant to full load condition is also considered. Second law analysis method is used with conversion of mass and degradation of quality of energy along with energy generation.

$(\eta)_{\text{second law}}$ = Exergy output/Exergy input

The exergetic efficiency is reported about 56.20% for collector-receiver assembly. The results of this analysis show similar tread reported by Xu et al. [24]
Energy and exergy analysis for solar tower power plant is evaluated by Xu at el. [24] by using molten salt as a HTF. DNI, concentration ratio and type of power cycle are also analyzes to evaluate theor effect on energy-exergy performance. They conclude that the main energy loss occur in the power cycle system but maximum exergy loss occur in

receiver system. By increasing DNI and concentration ratio, energy and exergy efficiencies can be increased. Also, by integrating advanced power cycles including reheat rankine cycles and supercritical rankine cycles, both efficiencies can be improved. The analysis of central receiver is based on thermal model which is modified from a validate model developed by Li et al [25]. Calculated energetic efficiency is 87.77% which satisfies with predicted value of 87.73% from Li's analysis and experimental average efficiency of 87.5% from Bergan's [25] experiment.

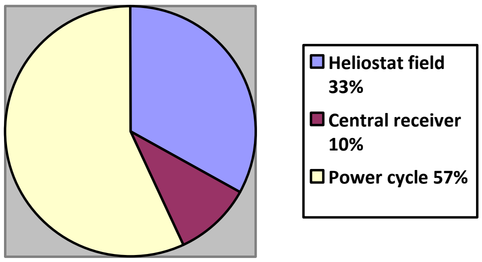

Fig. 5 Energy analysis [24]

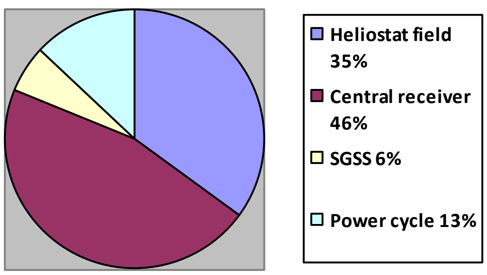

Fig 6 Exergy analysis [24]

Elsafi [26] carried an analysis for exergy and exergonomic with direct steam generation in parabolic trough solar thermal power plant by considering commercial size model. They conclude that the solar field has highest rate of exergy destruction followed by condenser. Third component with high rate of irreversibility is low pressure turbine. Solar field, low pressure turbine, high pressure turbine and condenser is sequence from exergoeconomic point of view based on values of total cost rate of each component.
The various designed parameters are listed in table 4.

Table 4 comparison of designed parameters

	[23]	[22]
Parameters	Value	Value
Absorber tube outer diameter	0.07 m	0.065 m
Absorber tube inner diameter	0.065 m	-
Intercept factor	0.92	0.95
Mirror reflectivity	0.92	0.93
Glass transmissivity	0.995	0.96
Solar absorptivity	0.94	0.88
Peak optical efficiency	0.75	-

Table 5 comparison of energetic-exergetic efficiency for subsystem

	[23]		[22]	
Subsystem	Energetic efficiency (%)	Exergetic efficiency (%)	Energetic efficiency (%)	Exergetic efficiency (%)
Collector	72.71	56.20	67.36	29.03
Receiver	93.91	69.56	64.88	68.38
Collector-receiver	66.89	39.09	43.70	19.85
Boiler	97.93	84.85	100.00	96.42
Overall	24.01	25.81	12.07	12.74

Below table 6 shows the energetic and exergetic analysis for subsystem of solar tower power plant.

Table 6 Energetic and exergetic efficiencies of solar tower power plant

Subsystem	Energetic efficiency (%)	Exergetic efficiency (%)
Heliostat field	75.00	75.00
Central receiver	90.02	55.48
SGSS	100	89.77
Power cycle	37.85	74.48
Overall	22.89	24.48

CONCLUSION AND RECOMMENDATION

An overview of development in solar thermal power plant technologies is presented to give an idea about how effectively solar energy can be utilize for power generation purpose. In this study, energy and exergy analysis is also discussed. From this analysis it is found that the main energetic loss takes place in condenser of heat exchanger for parabolic trough technology and in power cycle in central receiver technology. However it is also found that the main exergy loss takes place in collector-receiver assembly and in central receiver for parabolic trough and central receiver technology respectively. This technologies are useful to reduce green house gas emission and in meeting the global energy demand. However there is less progress in this field for commercial application, it is required to investigate this area to make it efficient for commercial purpose.

ABBREVIATIONS

HTF – Heat Transfer Fluid
DNI – Direct Normal Irradiation
CSP – Concentrated Solar Power
PTC – Parabolic Trough Concentrator
LFR – Linear Fresnal Reflector
CRS – Central Receiver System
PD – Parabolic Dish
STP – Solar Thermal Power
PDC – Parabolic Dish Concentrator

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