Prediction for the performance of a solar thermal power plant under the different climatic conditions across India

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Abstract - ***A solar thermal power plant of capacity 1 MWe is working at gurgaon near New Delhi. This plant is one of its own kinds as it has a combination of two fields that is parabolic trough collector having heat transfer fluid and linear Fresnel reflector having direct steam generation without any fossil fuel back up. To predict the performance of this solar thermal power plant a comparison has been done for the monthly average of hourly efficiency of PTC and LFR solar field, monthly average of hourly heat gain in PTC & LFR solar field, monthly average of hourly power output, monthly energy output of the plant and Plant factor under the climatic conditions of two states New Delhi and Jodhpur. This can help us to predict the performance of the same thermal solar power anywhere in India.***

Keywords: *Solar thermal power; parabolic trough collector; Linear Fresnel reflector; Predict; Performance*

1. INTRODUCTION TO SOLAR ENERGY

The huge demand for fuel has urged us to come up with a solution which can be long lasting and always available. From this thought the idea of solar power emerges and comes into picture. A comparison of the different solar technologies has been done by the Global Energy Network Institute [1]. India solar perspective has been given under the report India national solar mission [2].This solar energy is best being trapped by the two types of solar collectors which includes parabolic trough collector and linear Fresnel reflector. The parabolic trough collector has a tube having heat transfer fluid [3] which is used for processing. The performance of parabolic trough collector depends on various factors such as radiation of solar beam intensity, mass flow rate of oil, surrounding temperature, and inlet, outlet of collector temperature oil [4]. The linear Fresnel reflector produces steam directly from the water flowing through the tube attached with the reflector itself [5]. The performance of both these collector can be compared on different parameters [6]. The solar energy finds numerous applications in day to day life such as in heating the water, cooking but the most important is power generation. There are numerous solar power plants based on photovoltaic and thermal effect across the globe [7]. The solar thermal power plant set up at gurgaon near New Delhi in MW capacity is the first of its concept in India. It is a combination of parabolic trough collector having heat transfer fluid and linear Fresnel reflector having direct steam generation without a fossil fuel back up. The performance prediction for the solar power plant under the climatic conditions of New Delhi has been contrasted with the same solar thermal power plant but under the climatic conditions of Jodhpur. This prediction will help us to get the performance of the plant under the different climatic conditions across India which can be further used for its installation

2. CALCULATIONS FOR SOLAR COLLECTOR

The heat gain at collectors (Q_{gain}) and the efficiency of collector ($\eta_{collector}$) are given as [8]:

$$Q_{gain} = \dot{m}\cdot(h_{out} - h_{in}) = \eta_{collector} \cdot DNI \cdot Cos\theta \cdot A_p \quad (1)$$

$$\eta_{collector} = A - B \cdot \frac{(Tm - Ta)}{(DNI \cdot Cos\theta)} - C \cdot \frac{(Tm - Ta)^2}{(DNI . Cos\theta)} \quad (2)$$

here, DNI is direct normal irradiance in W/m², θ is incidence angle (take $\theta = \theta_{mean}$ for LFR, it is the average incidence angle which is calculated from incidence angle of every reflector rows), h is enthalpy in J/kg, ṁ is mass flow rate in kg/s, Ap is aperture area of collector in m², T_a is ambient temperature in °C, Tm is mean temperature in °C (Tin+Tout)/2, A is optical efficiency, B is first order loss co-efficient based on aperture area in W/m²-K and C is second order loss co-efficient based on aperture area in W/m²-K².

3. CALCULATIONS FOR TURBINE

The Power Output at the turbine is as given [8]:

$$Power\ (MWe) = a + b \cdot m + c \cdot \dot{m}^2 \quad (3)$$

Here a, b and c are the parameters of Willan's line equation and ṁ is for mass flow rate in kg/s

4. WORKING FLUID

It is important for a fluid to be thermally stable under particular heat transfer conditions. One of the advantages of liquid heat transfer is lower cost installation and operation [9]. The working fluid used here in the parabolic trough collector is Therminol VP1 [8]. The advantages of this fluid are uniform heat transfer, accurate temperature control, low mechanical cost of maintenance, and wide operating temperature range.

5. WORKING OF SOLAR THERMAL POWER PLANT

The plant works on two fields one is parabolic trough collector and other is linear Fresnel reflector field. The heat transfer fluid gets heated and is fed into the heat exchanger, where saturated steam is fed from the linear Fresnel reflector. The steam gets superheated and is further fed to the turbine. There are many ways for predicting the performance; one such way is taken as fixed conditions [8] at the inlet, outlet of collectors and turbine which is being controlled.

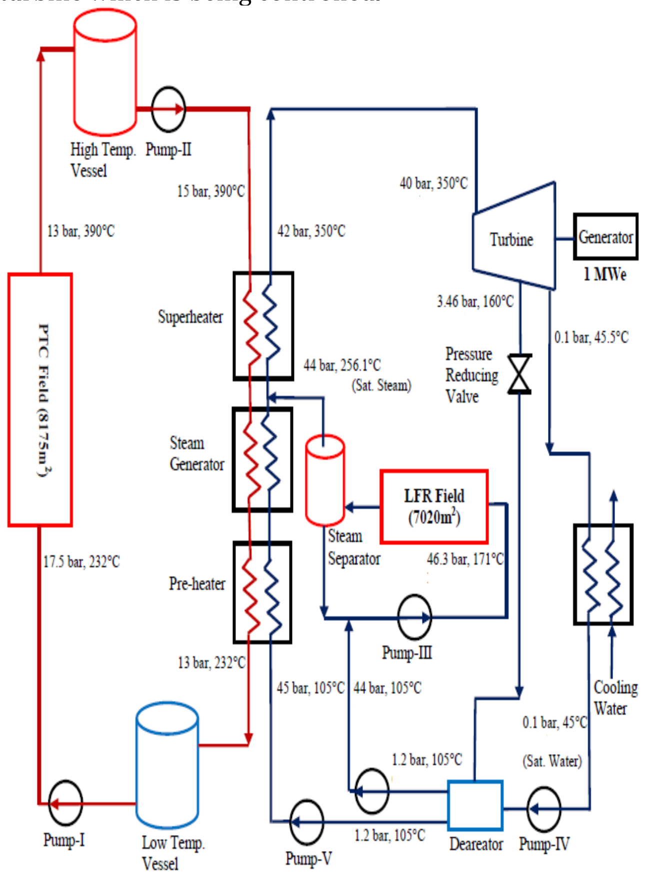

Fig-1 Flow diagram of solar thermal power plant at gurgaon [8]

6. CALCULATIONS

Under the climatic conditions for both Delhi and Jodhpur the following input parameters of PTC, LFR field and Turbine are used for calculations in equations (1), (2) and (3) [8]

PTC field: A_P = 8175 m^2, A=0.7, B=0.1, C=0, T_m=311ºC

LFR field: A_P = 7020 m^2, A=0.6, B=0.2, C=0, T_m=213.55ºC, h_{out}=1.6829 J/kg, h_{in}=0.7235 J/kg

The DNI, Ambient temperature (T_a), Incidence angle (θ) data was been taken with reference to Ramaswamy (2013) [10] and Tyagi (2009) [11]. The parameters taken for the prediction of the performance are the monthly average of hourly PTC efficiency, the monthly average of hourly heat gain in PTC field, the monthly average of hourly LFR efficiency, the monthly average of hourly heat gain in LFR field, the monthly average of hourly mass flow rate of fluid, the monthly average of hourly power output, the energy output in MWh/month and the plant factor.

The calculations shown are for the monthly average hourly basis of February at 9.00 a.m. for the above parameters for DELHI and JODHPUR.

DELHI

PTC EFFICIENCY (using equation 2)

$$\eta = 0.7 - 0.1 \frac{(311-13.5)}{(434.4 \; X \; COS54.8)} = 0.5811$$

PTC HEAT GAIN (using equation 1)

Q = 434.4×COS54.8×0.5811×8175 = 1.1895MW

LFR EFFICIENCY (using equation 2)

$$\eta = 0.6 - 0.2 \frac{(213.55-13.5)}{(434.4 \; X \; COS54.8)} = 0.4402$$

LFR HEAT GAIN (using equation 1)

Q = 434.4×COS54.8×0.4402×7020 = 0.7737MW

MASS FLOW RATE (using equation 1)

$$\dot{m} = \frac{0.7737}{(1.6829-0.7235)} = 0.8064\text{kg/s}$$

POWER OUTPUT (using equation 3)

P = -0.263+ (0.668×0.8064) = 0.2756MW

JODHPUR

PTC EFFICIENCY (using equation 2)

$$\eta = 0.7 - 0.1 \frac{(311-16.0)}{(640.4 \; X \; COS53.3)} = 0.6229$$

PTC HEAT GAIN (using equation 1)

Q = 640.4×COS53.5×0.6229×8175 = 1.9488MW

LFR EFFICIENCY (using equation 2)

$\eta = 0.6 - 0.2\,\frac{(213.55-16.0)}{(640.4 \, X \, COS53.3)} = 0.4967$

LFR HEAT GAIN (using equation 1)

Q = 640.4×COS53.5×0.4967×7020 = 1.3344MW

MASS FLOW RATE (using equation 1)

$\dot{m} = \frac{1.3344}{(1.6829-0.7235)} = 1.3908 kg/s$

POWER OUTPUT (using equation 3)

P = -0.263+ (0.668×1.3908) = 0.6661MW

Similarly calculations have been performed on monthly average hourly basis and the results have been shown.

7. RESULTS AND DISCUSSIONS

The maximum value for the monthly average of hourly PTC and LFR efficiency is mostly found to be between 11 a.m. and 1 p.m. of the day. The efficiency of both the fields under the climatic conditions of Jodhpur is found to be greater than the efficiency of same fields under the climatic conditions of New Delhi. The maximum value of PTC for Delhi is 65.55 % and that for Jodhpur is 65.87 % in the month of May. The maximum value for the monthly average of hourly power output (MWe) is found to be greater under the climatic conditions of Jodhpur than that for New Delhi. The maximum power output is 1.4434 MW for New Delhi and that for Jodhpur is 1.5153 MW in the month of May. The maximum value for the monthly average of hourly energy output (MWh/month) is found to be greater under the climatic conditions of Jodhpur than that for New Delhi. The maximum energy output is 264.525 MWh in the month of April for New Delhi and that for Jodhpur is 299.64 MWh in the month of May. The MWh generated per year for New Delhi is 1616.3181 and for Jodhpur is 2377.177. The plant factor for New Delhi is 18.45% and for Jodhpur is 27.13%.

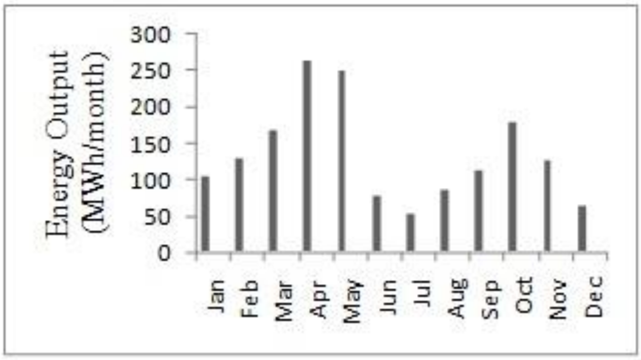

Chart-1: Monthly energy output of the plant under the climatic conditions of New Delhi

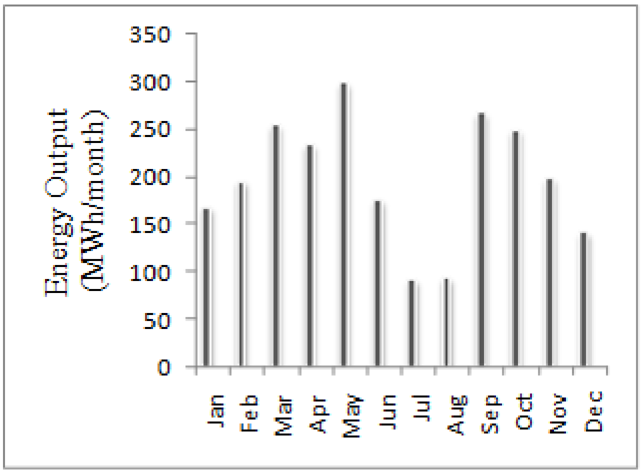

Chart-2: Monthly energy output of the plant under the climatic conditions of Jodhpur

8. CONCLUSION

Provided with the given infrastructure and support the same solar thermal power plant working at Gurgaon, generating 1616.3181 MWh energy annually with a plant factor of 18.45% would give 2377.177 MWh energy annually with a plant factor of 27.13% that is an increase of 760.8589 MWh energy annually and increase in the plant factor by 8.68 % if commissioned at Jodhpur. Similarly the calculations can be done for different locations across India and the performance prediction can be done to find out the maximum energy being generated by the plant.

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