Feasibility Study in terms of Technical and Levelized Cost of Electricity for Central Tower Receiver Power Plant in KarbiAnglong District, Assam

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Abstract : Feasibility of a 50 MW central tower receiver power plant both in terms of technical and financial parameters for KarbiAnglong district, Assam was performed in this project. Two software modeling PVsyst and System Advisor Model (SAM) were used in this work. Technical comparison was carried out on the basis of amount of electricity output obtained from SAM, whereas financial attractiveness was done on the basis of the amount of levelized cost of electricity (LCOE). The highest amount of electricity generation was obtained as 145.1 GWh and correspondingly LCOE was 9.67 Rs./kWh.

***IndexTerms* - Central tower receive (CTR), Levelized Cost of Electricity (LCOE), PVsyst and System Advisor Model (SAM).**

I. INTRODUCTION

Solar thermal energy technology such as concentrated solar power (CSP) systems uses the direct normal solar irradiance for energy generation and proven to be one of the best options among the available solar energy generation technologies. Therefore, selection of appropriate solar radiation data has a huge impact in modeling and designing of the CSP systems [1]. CSP systems are mainly divided into four parts. They are- parabolic trough collector, central tower receiver, linear Fresnel reflector and solar dish. Out of these available CSP systems central tower receiver has highest operating temperature and hence its annual efficiency. In India, solar power projects start getting importance after the Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) in which a target was set to generate 20 GW of grid-connected Solar power by 2022 [2]. That was again reset to generate 100 GW of solar energy by 2022 in 2014. Onsite DNI measurement requires the pyranometer. But due to the complexity involve in technicality and high cost of sensor make the ground measured data unavailable for all locations [3]. Therefore, satellite-derived data get more preference. Till 30th September 2018 total solar power installed capacity in India has reached up to 26 GW [4].

Toro et al. [5] performed exergy and thermoeconomic analyses of central receiver concentrated solar power plant using air as heat transfer fluid in J-CSP plant in Germany. Zhu et al. [6] made a techno-economic analysis of 100 MWe solar tower aided coal fired power generation system. Mustafa et al. [7] performed analytical study of an innovated solar power tower (PS10) in Aswan, Egypt. Weinrebe et al. [8] researched towards the holistic power tower system optimization.

In this paper, performance of a 50 MW CTR power plant is analyzed in terms of annual energy generation and LCOE.

II. WORKING PRINCIPLE

In solar tower receiver system a large number of solar reflector (called heliostats) are use to reflect the solar radiation by tracking the sun at two axes on to a central receiver located on a fixed tower. At the receiver, the heat transfer fluid (molten salt or air) absorb the solar energy reflected by the heliostat and is used to produce the steam to drove the turbine. A basic layout of central tower receiver is shown in Fig.1 [9].

The main advantage solar tower receiver is that very high temperature can be achieved which increases the efficiency of heat to electricity conversion. It also reduces the cost of thermal energy storage and raises the capacity factor.

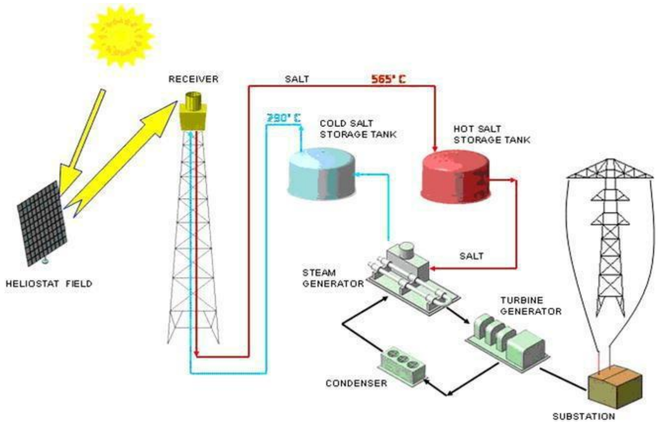

Fig.1. Central Tower Receiver

III. METHODOLODY

To perform the feasibility of a 50 MW central tower receiver system, the following mention methodology was adapted. Schematic diagram of methodology adapted is shown in Fig.2.

A.Selection of location

For this research purpose, KarbiAnglong district of Assam was considered because it contains the district-wise most number of the un-electrified villages [10]. The latitude, longitude and elevation of KarbiAnglong district are 26.11 N, 93.34 E and 182 meter respectively [11].

B. Selection of data sources

For performing the simulation of a 50 MW CTR power plant in System Advisor Model, solar radiation data along with other meteorological parameters are necessary. Solar radiation data are obtained from two sources, one is the onsite ground measurement and other is the satellite-derived. Satellite-derived data are the collected from various geostationary satellite located at different grid resolutions. In order to get the more accurate result, long-term ground measured data (at least 10 years of data of solar resources) are required [12]. Since ground measured data are site specific therefore for a location located 25 km distances from the where ground measurement is taken place, satellite-derived data are considered more favorable than the other one. For Assam there are only two locations where long term ground measurement data are available that is Guwahati and Tezpur. So for KarbiAnglong district no ground measure data are available. For that satellite-derived data were considered for this project. In Indian context there are few sources which provide the data for solar resources, such as- Meteonorm, NASA-SSE, NREL-SEC, PVGIS, SolarGIS, SWERA, RETScreen, 3Tier and ISHRAE. Out of these available data sources the data provided by NASA-SSE are same with RETScreen whereas NREL-SEC data are same with SWERA data source [13]. Meteonorm data source has several versions (Meteonorm 6, 7.0, 7.1 and 7.2), out of which latest being more accurate. For this project purpose we have considered Metronome 7.2, NASA-SSE, NREL-SEC, PVGIS and SolarGIS data sources. These data sources provides the monthly average daily values of solar radiation data such as global horizontal radiation, diffuse irradiation and direct normal irradiation along with several other meteorological parameters like temperature, wind speed, relative humidity etc. As the simulation was carried in System Advisor Model (SAM), SAM supports a Typical Meteorological Year (TMY) file which consists of hourly of solar radiation data. To obtain the hourly values from monthly average daily values synthetic hourly generation tool of PVsyst was used. In PVsyst hourly values are generated from monthly average daily values by using the Collares-Pereira &Rabl model. Firstly, this model generates a daily values from the monthly average values and then sequence of hourly values for 24 hours throughout a year [13]. After getting the hourly values TMY was created to determine the annual energy output. The Collares-Pereira &Rabl equation is shown in (1) [14].

$$r_t = \frac{\Pi}{4}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\Pi\omega_s}{180}\cos\omega_s} \quad (1)$$

Here a, b are coefficient, is the hour angle and ω_s is the sun-set hour angle (both in radian). The values of a, b are calculated by using (2) and (3) [14].

$$a = 0.409 + 0.5016(\sin\omega_s - 60) \quad (2)$$

$$b = 0.6609 - 0.4767(\sin\omega_s - 60) \quad (3)$$

C. Levelized cost of electricity estimation

The financial viability of the project was evaluated on the parameter of levelized cost of electricity (LCOE). All the benchmarking cost was considered as described by the Central Electricity Regulatory Commission of Government of India [15]. The LCOE calculation was base upon the following equation (4) [13].

$$LCOE = \sum_{i=1}^{25} \frac{UCE_i}{(1+d)^i} \times CRF \qquad (4)$$

Here UCE is the unit cost of electricity, CRF is the capital recovery factor, d is the discount rate and t is the useful life of the plant.

$$UCE_i = \frac{Total\ annual\ cost\ in\ i^{th}\ year}{Net\ annual\ electricity\ produced\ in\ i^{th}\ year} \qquad (5)$$

$$CRF = \frac{d(1+d)^t}{(1+d)^t - 1} \qquad (6)$$

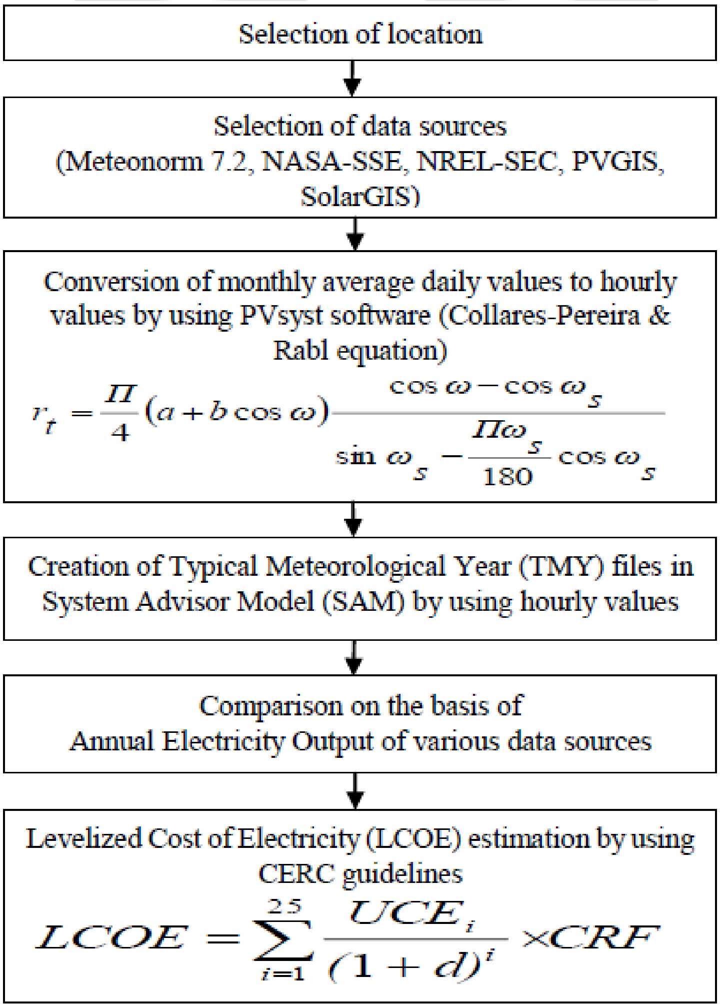

Fig.2. Schematic diagram of methodology adapted

IV. RESULTS AND DISCUSSIONS

The performance of a CTR plant is mainly depends upon the availability of the direct normal irradiation (DNI) besides the other design parameters [13]. The monthly average DNI values collected from selected data sources is presented in Table 1. From the Table 1 it is observed that the DNI values are higher in winter and lower in summer due to effect of the summer monsoon. After conversion of the monthly average daily values into hourly values, TMY files were generated to use them in System Advisor Model. By using this TMY files, simulation was carried out to estimate the annual energy yield. The annual energy output obtained from these five different data sources for 50 MW CTR systems is shown in Table 2. Design parameter for CTR system is shown in Appendix I.

Table 1: Monthly average DNI values of KarbiAnglong district provided by different sources

	Data Sources				
	Meteonorm 7.2 [16]	NASA-SSE [17]	NREL-SEC [18]	PVGIS [19]	Solar GIS [20]
Months	DNI ($kWh/m^2/day$)	DNI ($kWh/m^2/day$)	DNI ($kWh/m^2/day$)	DNI ($kWh/m^2/day$)	DNI ($kWh/m^2/day$)
January	5.77	6.79	4.24	5.01	6.38
February	5.39	6.48	4.84	5.45	5.62
March	4.26	5.70	4.49	4.84	4.13
April	3.63	4.73	4.16	4.08	3.26
May	3.45	3.48	4.06	3.60	2.81
June	3.07	2.90	3.29	2.98	2.37
July	3.10	2.82	3.32	3.19	2.63
August	3.06	2.99	4.13	3.33	2.84
September	4.17	3.16	4.49	3.68	3.69
October	4.23	4.43	4.89	4.23	5.38
November	6.37	6.37	6.06	5.66	7.53
December	7.77	6.95	5.67	5.55	7.64
Yearly Average	4.52	4.72	4.47	4.30	4.52

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Table 2: Annual Energy Output (GWh) for five data sources

Data Source	Annual Energy Output (GWh)
Meteonorm 7.2	128.6
NASA-SSE	130.2
NREL-SEC	145.1
PVGIS	138
SolarGIS	116.8

From the Table 2, it is seen that annual energy output is highest for NREL-SEC whereas it is lowest for SolarGIS data source. The reason for this is because of relatively lesser change in monthly average daily DNI values of NREL-SEC data source than the other data sources. Variation in beam normal (W/m2) is displayed in Fig.3. As cycle efficiency is the ratio of turbine output to boiler input, therefore turbine output will be higher when boiler input is low. The cycle efficiency was found highest for NREL-SEC with a value of 0.4619 that is 46.19% for the December month as shown in Fig.4. The levelized cost of electricity is conferred in Table 3. As greater energy yield reduces the levelized cost of electricity generation, it has been monitored in this case also. Since NREL-SEC data source generates the more annual energy its LCOE is lesser whereas SolarGIS data source which produces less annual energy its LCOE is higher compared to other selected data sources.

Variation in LCOE with respect to annual energy production is demonstrated in Fig.5. Also capacity factor is the ratio of actual energy output to the installed capacity of a power plant. In this research work installed capacity is assumed to 50 MW for all the selected data sources. Therefore higher the output energy higher will be the capacity factor. Since highest output was obtained from NREL-SEC data source, so it has the highest capacity factor. Capacity factor for all the considered data sources is given in Table 4.

Table 3: Levelized cost of Electricity (Rs./kWh) for five data sources

Data Source	Levelized cost of Electricity (Rs./kWh)
Meteonorm 7.2	10.87
NASA-SSE	10.74
NREL-SEC	9.67
PVGIS	10.64
SolarGIS	11.94

V. CONCLUSION

The outlook of the result is highlighted below-

- Five different data sources were considered in this research work. They were Meteonorm 7.2, NASA-SSE, NREL-SEC, PVGIS and SolarGIS respectively.

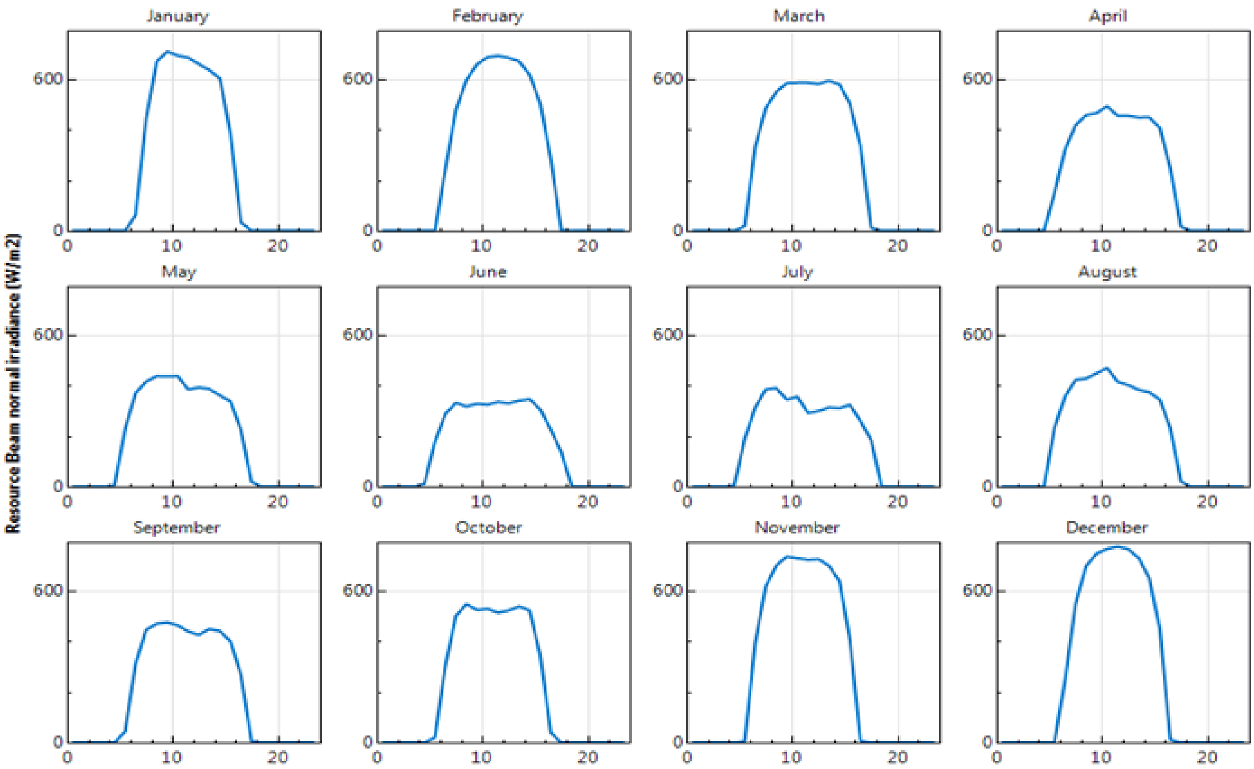

Fig.3. Beam normal irradiance (W/m2) for NREL-SEC data source for a year

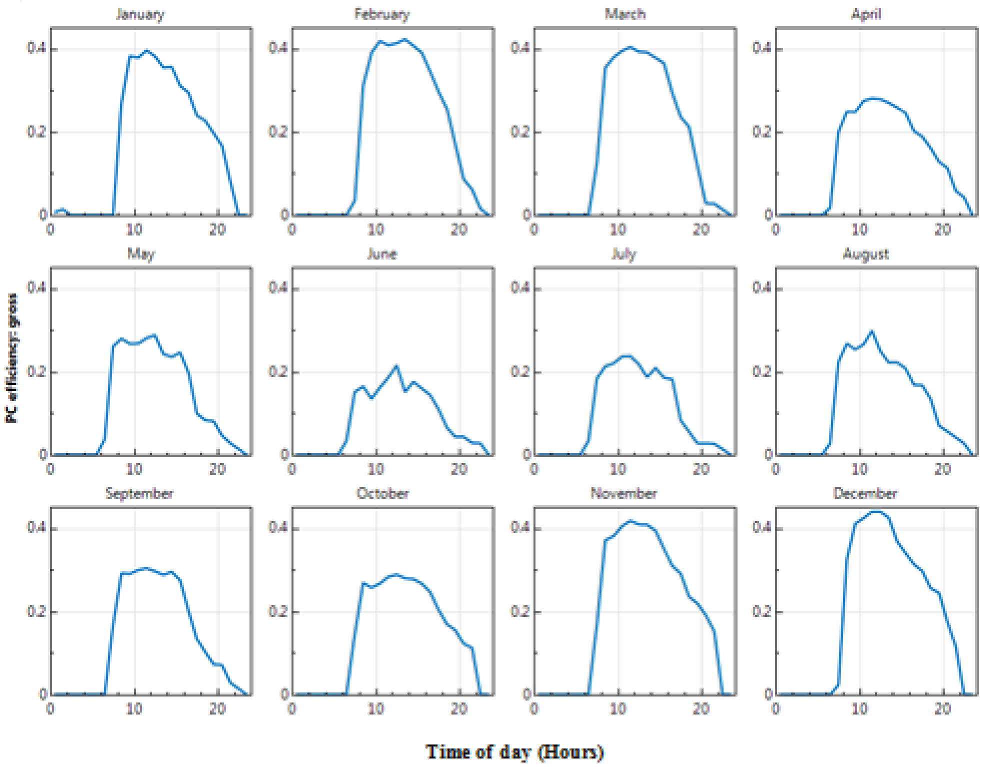

Fig.4. Cycle efficiency of central tower receiver plant for NREL-SEC data source

- Deviation in DNI values was lesser for NREL-SEC data source.
- Simulation was carried out to observe the annual energy output with the help of System Advisor Model (SAM).
- Annual energy output was highest for NREL-SEC whereas lowest for SolarGIS data source.
- Due to high annual energy yield for NREL-SEC data source, its levelized cost of electricity is lower.
- Cycle efficiency was found highest for NREL-SEC with a value of 0.4619 for the December month.

It is observed that variation of DNI affect the annual energy output hence in LCOE. Further studies can be made towards the variation in design parameters to see the improvement in thermal efficiency as well as in financial stability.

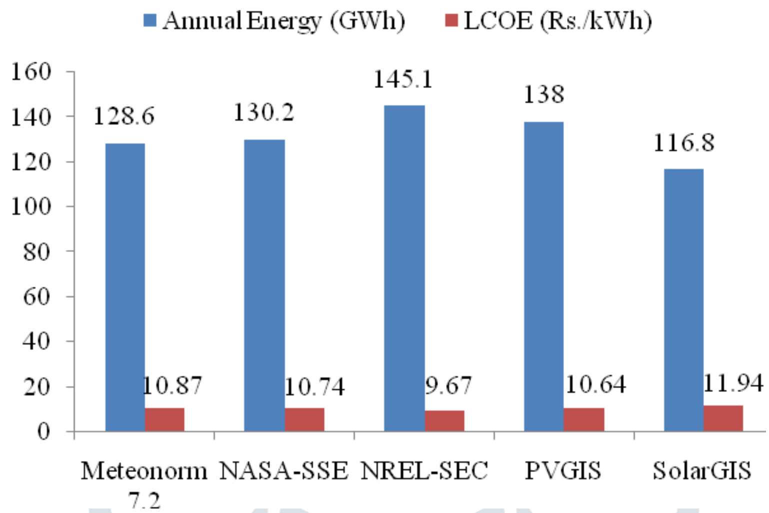

Fig.5. Annual energy output vs. LCOE for all the data sources

Table 4: Capacity factor for the selected data source

Data Sources	Meteo norm 7.2	NASA-SSE	NREL-SEC	PVGIS	SolarGIS
Capacity Factor	29.40%	29.70%	33.10%	31.50%	26.70%

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Appendix 1: Design specification of Central Tower Plant

Specification of Central tower Plant (SAM 2017)	
Parameter	Central Tower
Solar Multiple	2
Heat Transfer fluid	Molten Salt
Design point Inlet Temperature	290
Design point outlet Temperature	574
Heliostat Height	12.2 meter
Heliostat width	12.2 meter
Collector	Heliostats
Receiver	External
Nominal Capacity	50MW
Thermal Storage	6 hours
Year to year decline in output	Nil