Parametric Optimization and Performance Assessment of 50 MWe Parabolic Trough Power Plant

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ABSTRACT

Performance assessment and optimal sizing of Concentrated Solar Power (CSP) Parabolic Trough (PT) thermal power plant integrated with Thermal Energy Storage (TES) system is important to reduce Levelized Cost of Electricity (LCOE) and increase the system Annual Energy Generation (AEG). The main objective of this study is to perform optimization and feasibility analysis of a 50 MWe PT plant located at Hyderabad for optimum combination of Collector, Receiver and Heat Transfer Fluid (CRF) that will give maximum Capacity Factor (CF) and minimum LCOE. In PT power plant, solar radiations are concentrated through parabolic shaped collectors on to the receivers where energy is captured and stored with the help of heat transfer fluids. The multi-objective optimization technique is used which helps to find the optimized design and economic parameters in accordance with the Direct Normal Irradiance (DNI) profile of the location. The techno-economic assessment was simulated using System Advisor Model (SAM) software for ground measured data of Energy Sector Management Assistance Program (ESMAP) of the World Bank. The proposed plant was initially designed at Solar Multiple (SM) 2, TES 7.5 hours with air cooled and no backup system to find suitable combinations of CRF. The range of SM was kept from 1 to 3 with increment of 0.1 and TES hours from 4 to 15 with an increment of 0.5 for five best combinations of CRF to get optimized design parameters. The results indicate that the LUZ LS-3 collector, the Solel UVAC 3 receiver and the Caloria HT-43 heat transfer fluid are overall suitable choice for PT plant installation at SM 2.7 and TES 14.5 hours having low LCOE of 9.2 ¢/kWh and high CF of 79.4%. This study will help to optimize the design of PT power plants to conserve fossil fuels and increase their share in the global renewable energy mix.

Keywords: *Concentrated Solar Power, Parabolic Trough, Solar Multiple, Capacity Factor, Levelized Cost of Electricity, System Advisory Model.*

1. INTRODUCTION

Conventional energy resources have been a great driver in the economic development but high fluctuating prices, limited resources and environmental degradation make renewable sources of energy more attractive [1]. The world is also now admitting the competitiveness of renewable energy resources such as solar because of their abundant availability, environmental sustainability and potential to solve the problems associated with growing energy needs [2].

Solar energy can be converted into electricity using Photovoltaic (PV) and Concentrated Solar Power (CSP) technologies. CSP technologies have advantage over the Solar PV technology because of its Thermal Energy Storage (TES) system during the non-solar hours of the day, resulting in high Capacity Factor (CF) and Annual Energy Generation (AEG) [3]. Initial cost of CSP was quite high as compared to PV but with the advancement in technology and parametric optimization total installed cost has been fell by 50% for CSP plants in between 2010

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and 2020 as per reports by International Renewable Energy Agency (IRENA) [4].

Parabolic Trough (PT) technology of CSP is used in the present study which concentrates the solar radiations through parabolic shaped collectors on to the receivers where energy is captured and stored with the help of heat transfer fluids [5]. This stored energy is then used to produce steam to generate electricity with the help of steam turbine. CSP plant installation requires feasibility analysis which includes solar energy resource, performance assessment and cost estimation. The present study compares techno-economic feasibility of PT plant equipped with more than 10 thermal energy storage hours system for different collector, receiver and heat transfer fluid combinations to find the optimum combination for Hyderabad location that will give maximum CF and minimum Levelized Cost of Electricity (LCOE).

2. METHODOLOGY

The solar radiation data was measured by Energy Sector Management Assistance Program (ESMAP) of the World Bank at nine solar meteorological stations across Pakistan during the years 2014 to 2017 [6]. Tier 1 and Tier 2 systems have been used to measure this data. The measured data of Hyderabad was used in the present study. Tier 2 system coupled with CSP Services Twin-Sensor Rotating Shadowband Irradiometer (RSI) was used to measure Global Horizontal Irradiance (GHI), Diffused Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI) for Hyderabad from 21st of April 2015 to 31st of Jan 2017. Campbell Scientific CS215 was set up to measure ambient Temperature (T) having accuracy of ±0.3% at 25°C and Relative Humidity (RH) having accuracy of ±2% at 25°C [7]. Data quality was checked using the Standard Operating Procedure for the Baseline Surface Radiation Network (BSRN) [8].

System Advisory Model (SAM) was used for performance assessment and optimization of input parameters of Parabolic Trough (PT) power plant. The input parameters include the collector, receiver, heat transfer fluid, Solar Multiple (SM), Thermal Energy Storage (TES) hours, and fixed financial parameters of Pakistan. The multi-objective optimization technique was used to get the desired output parameters including Capacity Factor (CF) and Levelized Cost of Electricity (LCOE). The Design point Direct Normal Irradiance (DNI) values for Hyderabad were taken on the summer solstice at solar noon as recommended by SAM for PT technology [9]. Standard Solar field and fixed pressure air-cooled Rankine cycle were used for a 50 MWe PT plant as defined by National Renewable Energy Laboratory (NREL) for concentrated solar power PT plant [10]. The details of nine collectors, eight receivers and nine heat transfer fluids are mentioned in Table 1. Total 648 combinations were made to find optimum combination using multi-objective optimization approach. The TES hours were kept from 4 to 15 with the increment of 0.5 and solar multiple range was 1 to 3 with the increment of 0.1. The process included 3063 simulations to identify the optimized and best performing CRF combination against the SM and TES hours to provide the highest CF and lowest LCOE.

3. RESULTS AND DISCUSSION

3.1. Optimization of Collector, Receiver and Heat Transfer Fluid

The Collector, Receiver and Heat Transfer Fluid (CRF) are optimized at Solar Multiple (SM) 2 and Thermal Energy Storage (TES) hours 7.5 because most of the currently operational parabolic trough plants are working on these values of SM and TES hours. Total 648 combinations were made and five optimized combinations of CRF that will give maximum capacity factor and minimum levelized cost of electricity are selected and listed in Table 2.

Table 1. Collectors, Receivers and Heat Transfer Fluids for Parabolic Trough Plant

Collectors	Receivers	Heat Transfer Fluids
C1: Euro Trough ET150	R1: Schott PTR70	F1: Hitec Solar Salt
C2: Luz LS-2	R2: Schott PTR70 2008	F2: Caloria HT43
C3: Luz LS-3	R3: Solel UVAC 3	F3: Hitec XL
C4: Solargenix SGX-1	R4: Siemens UVAC 2010	F4: Therminol VP-1
C5: Albiasa Trough AT150	R5: Schott PTR80	F5: Hitec
C6: Siemens SunField 6	R6: Royal Tech CSP RTUVR 2014	F6: Dowtherm Q
C7: SkyFuel Sky Trough	R7: Royal Tech CSP RTUVR 70M4	F7: Dowtherm RP
C8: FLABEG Ultimate Trough RP6 (with 89-mm OD receiver for oil HTF)	R8: TRX-Solar TRX70-125	F8: Therminol 59
C9: FLABEG Ultimate Trough RP6 (with 70-mm OD receiver for molten- salt HTF)		F9: Therminol 66

Table 2. Optimized CRF Combinations for Hyderabad

Combination	C3R3F2	C3R7F2	C3R3F9	C5R3F9	C7R3F9
Capacity Factor (%)	55.8	56.0	55.2	55.1	55.3
LCOE (¢/kWh)	9.81	9.86	9.91	9.80	10.03

3.2. Optimization of SM and TES hours

The range of SMs was kept from 1 to 3 and TES hours from 4 to 15 in order to study the effect of SM and TES hours on the techno-economic parameters of PT plant for five CRF combinations as mentioned in Table 2. The optimization results show that the increase in TES hours results in increase in Capacity Factor (CF) and decrease in the Levelized Cost of Electricity (LCOE) for a specific SM value. The decrease in LCOE continues with the increase in TES hours until a certain value after this value the increase in TES hours results in increase in LCOE. The increase in LCOE is because the cost of adding more thermal storage becomes progressively higher than the additional annual energy generation at higher value of TES hours. The simulation results for five different combinations of CRF are mentioned in Table 3.

The optimization results show that maximum CF and minimum LCOE values are 79.4% and 9.20 ¢/kWh respectively for Hyderabad location at SM 2.7 and TES 14.5 hours for the best combination of C3R3F2 as shown in Figure 1 and Figure 2 respectively.

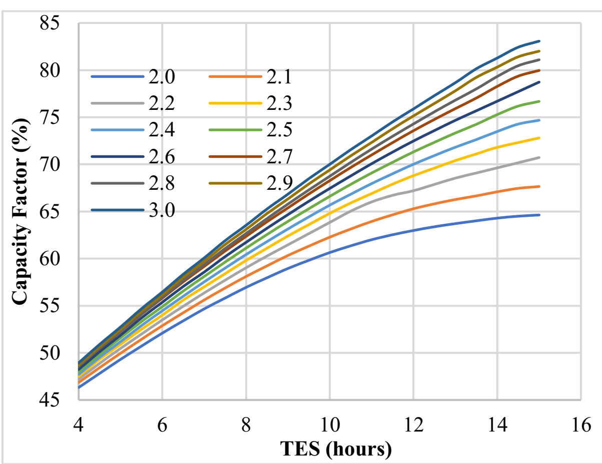

Figure 1 The variation of capacity factor versus thermal energy storage hours for different values of solar multiple

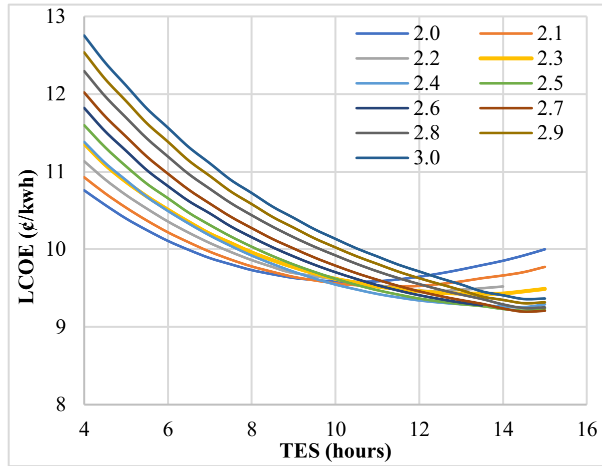

Figure 2 The variation of levelized cost of electricity versus thermal energy storage hours for different values of solar multiple

5. CONCLUSION

In the present study, design, performance, and economic analysis of a 50 MWe concentrated solar power parabolic trough plant with thermal energy storage system has been performed for Hyderabad site located in Pakistan to estimate Capacity Factor (CF) and Levelized Cost of Electricity (LCOE). It has been found that LCOE and CF depends upon the combination of collector, receiver and heat transfer fluid, and range of Solar Multiple (SM) and Thermal Energy Storage (TES) hours. The simulation results for the proposed plant show that combination of the Luz LS-3 collector, the Solel UVAC 3 receiver and the Caloria HT-43 thermal fluid (C3R3F2) at SM 2.7 and TES 14.5 hours resulted in low LCOE of 9.2 ¢/kWh and high CF of 79.4% for Hyderabad location.

AUTHORS' CONTRIBUTIONS

Zia ul Rehman Tahir: Conceptualization, Methodology, Investigation, Validation.

Tariq Ali: Methodology, Investigation, Validation, Writing, Formatting

Table 3. Optimized Design Parameters for Hyderabad

Combination	C3R3F2	C3R7F2	C3R3F9	C5R3F9	C7R3F9
Capacity Factor (%)	79.4	78.4	79.0	79.1	79.1
LCOE (¢/kWh)	9.20	9.37	9.39	9.30	9.4
Solar Multiple	2.7	2.6	2.7	2.7	2.7
TES Hours	14.5	14.5	14.5	15	14.5

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