# *Performance Assessment of 50 MWe Concentrated Solar Power Linear Fresnel Reflector Power Plant in Pakistan*

Zia ul Rehman Tahir[1,*], Muhammad Ahmad Nisar[1], Tariq Ali[1], Muhammad Fahad Mukhtar[1], Ahmad Hassan[1], Talal Ahmed Awan[1], Muhammad Afnan Mohsin[1], Fazeel Asghar[1], Hafiz Shahzad Siddiqi[1], Muhammad Azhar[1,2], Waheed ul Hassan Rasheed[1], Talha Akhtar[1], Muhammad Asim[1]

[1] *Department of Mechanical Engineering, University of Engineering and Technology Lahore, Pakistan*
[2] *Department of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK*
[*]*Corresponding author. Email: ziartahir@uet.edu.pk*

**ABSTRACT**

Global energy trends have led to development of Concentrated Solar Power (CSP) technology in which Linear Fresnel Reflector (LFR) has served as the best alternative for conventional energy production. Solar radiations are concentrated through flat or slightly curved reflectors on to receiver tubes through which either water flows and steam is directly generated, or Heat Transfer Fluids (HTFs) are used to store captured energy in storage tanks. Performance assessment of LFR plant integrated with Thermal Energy Storage (TES) system and Direct Steam (DS) system is an essential element to reduce Levelized Cost of Electricity (LCOE) and to increase Capacity Factor (CF). This study presents comparative analysis of 50 MWe LFR-DS and LFR-TES plant for a potential location to achieve a system with maximum CF and minimum LCOE. System Advisor Model (SAM) utilized the solar radiation data measured by Energy Sector Management Assistance Program (ESMAP) of the World Bank for the performance assessment and optimization of CSP-LFR plant. Nine HTFs were used and the best HTF was selected based on its thermal properties along with the desired CF) and LCOE. The Solar Multiple (SM) was optimized for the DS system, while both the TES-hours and SM were optimized for the TES system. The results indicate that for the TES system, Hitec is the best performing HTF operating at SM 4.4 and TES 16 hours with LCOE 6.7 ¢/kWh and CF 78.42 % whereas for DS system LCOE is 12.04¢/kWh and CF is 26.92 % at SM 1.8. The comparison reveals that the TES is more efficient than the DS system because of its high thermal storage capacity for the operation of LFR plant during off-solar hours.

***Keywords:*** *Linear Fresnel Reflector, Solar Multiple, Capacity Factor, Levelized Cost of Electricity, System Advisory Model.*

## 1. INTRODUCTION

Energy and environmental crisis, economic burden and depletion of non-renewable resources have been key factors leading towards the use of clean and green energy [1]. The global acceptance of solar energy for its advantages to deal with the energy problems is due to its excess amount, eco-friendly behaviour and role in economic development [2]. The replacement of conventional plant with solar cycle can be achieved by utilizing two major technologies, Photovoltaic (PV) and Concentrated Solar Power (CSP). CSP systems are preferred over PV because of their high thermal storage capacity, low cost and efficient power production [3]. It can achieve high temperature ranges to attain energy requirements in various applications.

The line focusing CSP technology known as Linear Fresnel Reflector (LFR) operates on different systems including Thermal Energy Storage (TES) and Direct Steam (DS). LFR-TES consists of either flat or slightly curved reflectors, upon which incident solar radiations is reflected and collected on evacuated absorber tubes through which Heat Transfer Fluids (HTF) absorbs heat and stores it in TES tanks [4]. LFR-DS consists of the same assembly but differentiates in the unavailability of


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storage system against which a recirculated boiler is used for steam generation [5].

The TES system utilizes stored heat energy in steam production to generate electricity from the steam turbine and the DS system simply uses the recirculated steam to generate electricity from the turbine. Setting up an LFR-CSP plant requires the performance assessment and cost estimation by means of available solar energy resource. The aim of study is to perform comparative analysis of a 50 MWe LFR power plant using direct steam system and thermal energy storage system in terms of capacity factor and levelized cost of electricity for a potential location in Pakistan.

## 2. METHODOLOGY

The analysis utilized the solar radiation data measured by Energy Sector Management Assistance Program (ESMAP) of the World Bank for time duration 2015 to 2017 [6]. The measured data of Khuzdar was used in the present study. Concentrated Solar Power (CSP) Services Twin-Sensor Rotating Shadowband Irradiometer (RSI) is used for measurement of required parameters such as Global Horizontal Irradiance, and Direct Normal Irradiance (DNI) and the annual Diffused Horizontal Irradiance with the accuracy of RSI less than 2 % [7]. The Campbell Scientific CS 215 was equipped with measuring system to measure ambient Temperature (*T*) and Relative Humidity (RH) having tolerance of ±0.3°C at 25° C and of ± 2 % at 25°C respectively. The Baseline Surface Radiation Network (BSRN) was used as a standard method check quality control of solar radiation data [8].

System Advisor Model (SAM) is a techno-economic software developed by National Renewable Energy Laboratory (NREL) which was used for performance assessment and optimization of concentrated solar power Linear Fresnel Reflector (LFR) plant. The DNI values recommended by SAM, typical meteorological format for solar radiation data, Heat Transfer Fluid (HTF), financial parameters are of prime importance for adequate operation of LFR. The fundamental conditions of site selection for LFR power plant include that it should receive more than 1800 kWh/m$^2$/year (5 kWh/m$^2$/day) of DNI [9], ground slope ranging between 1-3 %, wind speed must not be greater than 5.64 m/s, infrastructural requirements including water resources, transport facilities and grid connectivity. In Pakistan, Khuzdar meets all the requirements that made it the potential site for LFR power plant. The designed LFR plant operates on steam Rankine cycle with nominal capacity of a 50 MWe.

Nine HTFs; Hitec, Hitec XL, Hitec solar salt, Dowtherm Q, Dowtherm RP, Therminol VP-1, Therminol 59, Therminol 66 and Caloria HT were used. The best HTF was selected based on its thermal properties along with the desired Capacity Factor (CF) and Levelized Cost of Electricity (LCOE). The process involved 690 iterations for each HTF using different combinations of Solar Multiple (SM) from 1.5-6 with the increment of 0.1 and Thermal Energy Storage (TES) hours ranging from 4-18 with the increment of 1, as suggested by International Renewable Energy Agency (IRENA) 2022 for optimal performance of LFR plant integrated with TES system. The loop flow configuration in Direct Steam (DS) system was defined as recirculated boiler for which 46 iterations were performed with the same SM range. This parametric technique yields maximum CF and minimum LCOE for both systems.

## 3. RESULTS AND DISCUSSION

### *3.1. Optimal Solar Multiple and Thermal Energy Storage Hours*

The ranges of Solar Multiple (SM) and Thermal Energy Storage (TES) hours were kept from 1.5-6 and 4-18 respectively to meet the prime objective for the techno-economic analysis of the Linear Fresnel Reflector (LFR) plant to achieve minimum value of Levelized Cost of Electricity (LCOE) and a maximum value of Capacity Factor (CF). The parametric analysis resulted in optimum values of SM and TES hours with maximum CF and minimum LCOE. The optimum values are presented in Table 1.

**Table 1.** Optimized Design Parameters for Khuzdar

| Thermo-Fluids | Capacity Factor (%) | LCOE (¢/kWh) | Solar Multiple | TES Hours |
|---|---|---|---|---|
| Hitec | 78.42 | 6.7 | 4.4 | 16 |
| Hitec XL | 78.8 | 6.8 | 4.5 | 16 |
| Dowtherm Q | 73.81 | 6.5 | 3.9 | 14 |
| Dowtherm RP | 73.87 | 6.5 | 3.9 | 14 |
| Therminol VP1 | 72.27 | 6.5 | 3.8 | 13 |
| Therminol 59 | 57.43 | 11.1 | 4.9 | 15 |
| Therminol 66 | 64.89 | 9.6 | 4.9 | 16 |
| Hitec Solar Salt | 77.62 | 6.8 | 4.4 | 16 |
| Caloria HT | 72.86 | 6.7 | 3.9 | 14 |

The Figure 1 shows an increasing relation between TES hours and CF for the specific SM value. The increase in SM value will acquire more solar energy available to the Heat Transfer Fluids resulting in enhanced storage capacity However, LCOE decreases with increase in TES hours, but it begins to increase after certain value of TES hours due to additional cost of installing storage system comprising of larger storage tanks and more HTF as shown in Figure 2. The optimization results show that maximum CF and minimum LCOE values are 78.42% and 6.7¢/kWh respectively for Khuzdar location at SM 4.4 and at TES 16 hours for the best HTF Hitec.

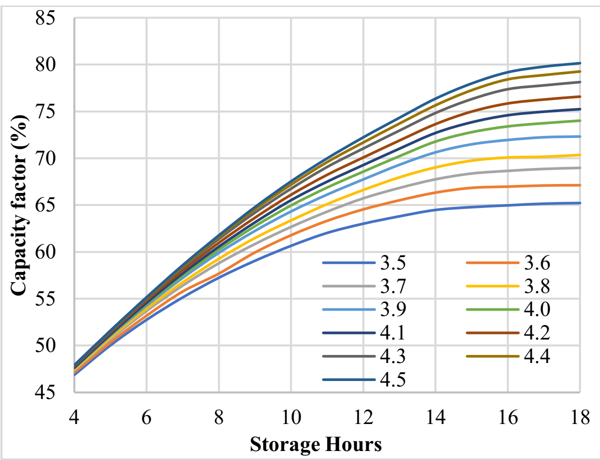


**Figure 1** Capacity factor variation versus thermal storage hours for different values of solar multiple

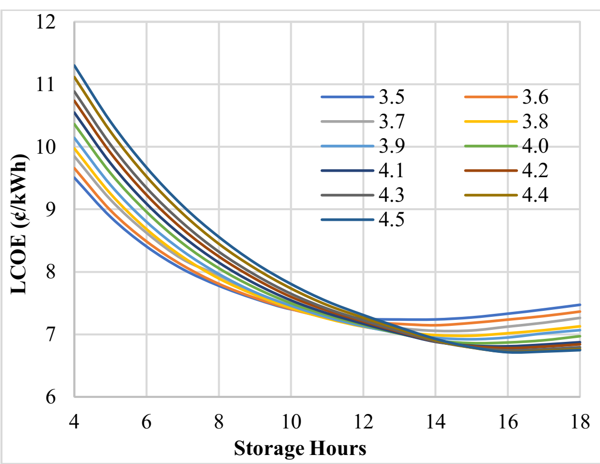


**Figure 2** Levelized cost of electricity variation versus thermal storage hours for different values of solar multiple

### *3.2. Comparison between Direct Steam and Thermal Energy Storage Systems*

A comparative analysis was performed for Thermal Energy Storage (TES) system and Direct Steam (DS) system using the solar multiple range of 1.5-6 to find out the minimum LCOE and maximum CF for one of the systems using optimization process. The results are presented in Table 2, and it was found that TES system is better performing with maximum CF and minimum LCOE than DS because HTFs have high liquid phase operating temperature between 500°C-1000°C with little or no vapor pressure and thus they do not need special pressurized tanks for storage reducing the capital cost.

## 4. CONCLUSION

A 50 MWe Concentrated Solar Power Linear Fresnel Reflector (CSP-LFR) plant based on Rankine cycle with Thermal Energy Storage (TES) system and Direct Steam (DS) system is designed for comparative analysis to achieve optimum values of LCOE and CF. A designed model is simulated using System Advisor Model (SAM) software for the selected site, Khuzdar. It was found that performance of plant mainly depends upon three parameters (Heat Transfer Fluid, Solar Multiple, TES hours). It is concluded that for TES system, Hitec is the best HTF at optimized conditions with CF of 78.41% and LCOE of 6.71¢/kWh because of its thermal ability to achieve high temperature among other Heat Transfer Fluids (HTF). It was identified that the Therminol-59 is the least performing HTF for the plant with the lowest CF of 57.4 % and highest LCOE of 11.12 ¢/kWh due to its low thermal abilities. In comparison, for DS system minimum LCOE is 21.2 ¢/kWh and maximum CF 33.5 % which is not much feasible for the performance of plant. This study would closely predict optimum working conditions and economic feasibility for LFR technology.

## 5. AUTHORS' CONTRIBUTIONS

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

**Muhammad Ahmad Nisar:** Original Draft, Writing, Formal Analysis.

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

**Ahmad Hassan:** Review/Editing, Formatting

**Talal Ahmed Awan:** Original Draft Writing, Formal Analysis.

**Table 2.** Comparison between Direct Steam and Thermal Energy Storage Systems

| LFR System | Solar Multiple | Max Capacity Factor (%) | Min LCOE (¢/kWh) |
|---|---|---|---|
| Direct Steam | 1.8 | 26.9 | 12.0 |
| Thermal Energy Storage | 4.4 | 78.4 | 6.7 |

**Muhammad Afnan Mohsin:** Original Draft Writing, Formal Analysis.

**Muhammad Fahad Mukhtar:** Review/Editing.

**Fazeel Asghar:** Writing, Review/Editing.

**Hafiz Shahzad Siddiqi:** Review/Editing.

**Muhammad Azhar:** Writing, Review/Editing.

**Waheed ul Hassan Rasheed:** Review/Editing.

**Talha Akhtar:** Review/Editing.

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