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Comparative Study of Levelized Cost of Electricity (LCOE) for Concentrating Solar Power (CSP) and Photovoltaic (PV) Plant in the Southeastern Region of Bangladesh

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Abstract— **Most of the renewables particularly Solar PV are intermittent. For this, dispatchable energy sources are required in the energy mix. Concentrated Solar Power (CSP) is dispatchable in nature. The aim of this work is to conduct the feasibility study of Parabolic Trough, Power Tower and Solar PV plant (with and without battery storage) and compare their performances. As south-east part of Bangladesh has better solar potential, four locations of Chittagong (Bashkhali, Sandwip, Maheshkhali, and Vashan Char) are taken as reference places. During evaluating the feasibility study, various ratings of power plants like 200MW, 150MW, 100MW, 50MW, 25MW, 5MW have been considered. Finally, optimization has been conducted with respect to Solar Multiple (SM) and Thermal Energy Storage (TES). System Advisor Model (SAM) has been used to perform the simulation work. Optimized results of CSP plants have been compared with the same MW grid-connected PV power plants. Results show that Solar PV plant has better performance compared with CSP. Among the four locations, BASHKHALI is the best for implementing solar power plants.**

Index Terms—CSP; DNI; Parabolic Trough; Power Tower; PV.

I. INTRODUCTION

The global demand for energy is rising day by day due to increase in population. While demand is increasing in developing countries; Developed countries continue to consume big amounts of energy. Energy needs are projected to expand by 55% Between 2005 and 2030 [1]. Still, 80% of the world's energy is delivered by fossil fuels which are making critical mischief to the earth [2]. Burning the fossil fuel is causing a tremendous harm to our environment. It produces harmful CO_2 and other greenhouse gasses [3].

For this reasons, we cannot waste more time. It's high time to break our close bonding with conventional energy systems. We need to shift to the 100% renewable energy as early as possible.

Excluding conventional biomass, the share of modern renewables in energy consumption was 10.40% in 2016. 3.4% of this consumption came from hydropower and other sources such as solar, wind, geothermal etc shares the rest. As we have seen earlier, around 80% of the consumption came from fossil fuels [4].

The capacity of Solar PV reaches to 402GW at the end of 2017, which was 303GW in 2016. So we can see a 100GW increase in Solar PV capacity in just one year. Now if the growth of CSP is compared to Solar PV, we can see a relatively slow growth for CSP. Worldwide the installed capacity of CSP was 12.8GW at the end of 2017, which was 12.3GW in 2016. So we can see only 0.5GW increase in CSP capacity. Currently, 30% of world electricity is generated from the renewables [4].

Like the world, most of the electricity is produced from fossil fuels in Bangladesh. However, the government is aiming to produce 10% of its electricity from renewables especially from Solar PV by 2021. The maximum electricity of Bangladesh is generated from the natural gas. It is almost 65%. Only 2% of our electricity is generated from renewables. Bangladesh Government has a target of producing 24000MW in 2021, 40000MW in 2030 and 60000MW in 2041 [5]. In 2015, SREDA and Power Division of GOB has taken a master plan called 'Energy Efficiency and Conservation Master Plan up to 2030'. This plan aims to improve energy intensity by 20% in 2030 [6].

The average monthly solar radiation in the country is 136-287 W/m^2. Throughout the year solar radiation ranges from 1500 W/m^2/day to 2750 W/m^2/day in our country; especially in Chittagong and Cox's bazar regions. So southern part of Bangladesh where annual solar DNI is above 5 kWh/m^2/day is suitable for solar power technologies [7].

1) CSP Technologies: Here Two CSP technologies (Parabolic Trough and Power Tower) among the four available technologies (Parabolic Trough, Power Tower, Linear Fresnel Plant and Solar Dish Plant) are considered for our study.

a) Parabolic Trough: Parabolic Trough systems utilize bent mirrors to center the sun's beam onto a receiver tube. In this tube, a high-temperature heat exchange fluid absorbs the sun's energy which is shown in Fig. 1. [8]

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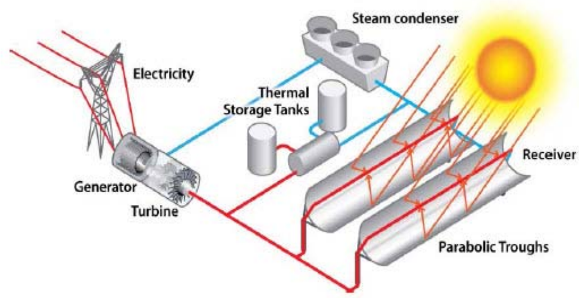

Fig. 1. Parabolic Trough technology [9].

b) Solar Tower: Solar Tower technologies usually utilize a ground-based field of mirrors to focus the sun-powered light onto a collector on a tower which is shown in Fig. 2. [10]

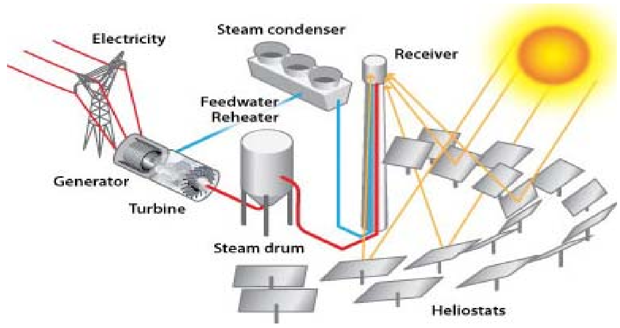

Fig. 2. Solar Tower power plant [11].

2) Photovoltaic(PV) Technology: PV is electronic devices that convert solar energy directly into electricity. Solar PV frameworks can be partitioned into two kinds: independent PV systems and grid-connected PV systems which are shown in Fig. 3 .[12]

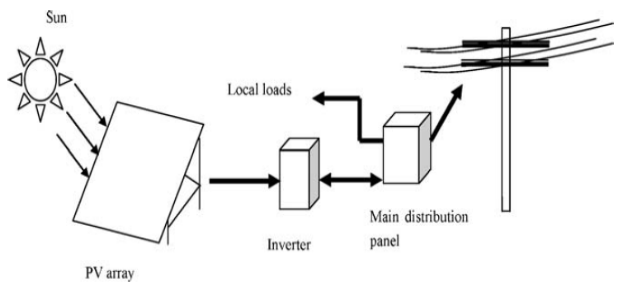

Fig. 3. Grid-connected PV power system [12].

In this paper, we will conduct the feasibility study of CSP with the thermal storage system and PV in Chittagong, Bangladesh.

II. Literature Review

Islam, Shima, and Khanam in 2012 have analyzed the grid-connected Solar PV system for Bangladesh. Cost of per unit electricity is found $ 0.20 on 25 years project lifetime. PV can reduce the greenhouse gas emission and produce a clean energy [13]. Hussain and Adnan in 2013 proposed that CSP with TES can be economically profitable for Bangladesh [14]. Mohammad and Ahmed in 2014 showed that a grid-connected PV with battery backup can be a good choice for Bangladesh [15]. Jorgenson and Paul in 2015 investigated that some configurations of CSP with TES had shown lower net cost than PV with batteries [16]. Dieckmann, Taylor, and Pablo in 2016 calculated LCOE for 2015 and 2025 of the NOOR II+III plants in Morocco [17].

III. System Architectural Design

A. Locations Selection and Data Acquisition

We have seen from Fig. 4 that the southern part of Bangladesh is good for solar power generation. Especially South-east part of Chittagong is best for site selection [18]. Considering the land cost and availability of huge space we've chosen four locations i.e. Bashkhali, Maheshkhali, Sandwip & Vashanchar which are shown in TABLE □ [19] .We have collected our data from NSRDB Data Viewer powered by NREL which is shown in Fig. 5 [19].

TABLE I. Basic Topographical Features of Four Locations

Topographical Feature	Bashkhali	Maheshkhali	Sandwip	Vashanchar
Latitude	22.05°N	21.55 °N	22.55°N	22.35 °N
Longitude	91.95 °E	91.95 °E	91.45°E	91.45 °E

B. System Description

In this study, two CSP technologies such as Parabolic Trough and Power Tower have selected. With this PV without battery and with battery are considered. The NREL's SAM is used to model 200 MW CSP plants (Parabolic Trough and Power Tower) with the same power rating PV with and without battery. The values of system specifications for 200 MW CSP plants (Parabolic Trough and Power Tower) with the same power rating PV with and without a battery are given in TABLE II [20], [21], [22], TABLE III [21], [23], [24], [25], [26] and TABLE IV [27], [28], [29] respectively.

TABLE II. System Specifications For Parabolic Trough Plant

Parameters/Variables	Values
Solar Multiple	2.7
Heat Transfer Fluid/TES/Receiver Fluid	THERMINOLVP-1
Collector	Euro Trough ET 150
Collector Tilt and Azimuth Angle	Equal to latitude and 0 degree
Receiver	Schott PTR 80
Design Point DNI	800 w/m^2
Thermal Storage Hours	15 Hours

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Tank Height	15 m
Land	1165 acres
Condenser	Air Cooled
Power Cycle	Rankine Cycle

TABLE III. System Specifications For Power Tower Plant

Parameters/Variables	Values
Solar Multiple	2
Heat Transfer Fluid/TES/Receiver Fluid	Molten Salt
Number of Heliostats	13300 (optimized)
Collector Tilt and Azimuth Angle	Equal to latitude and 0 degree
Tower Height	211.173 m
Design Point DNI	800 w/m^2
Thermal Storage Hours	15 Hours
Tank Height	15 m
Land	3143 acres
Condenser	Air Cooled
Power Cycle	Rankine Cycle
Inflation Rate	6.68 %
Debt fraction	100 %
Loan/Debt interest rate	11 % /year
Income Tax rate	30% /year
Sales tax (VAT)	5 % of the total direct cost

TABLE IV. System Specifications For Photovoltaic(PV) Plant

Parameters/Variables	Values
Module Per String	28 (calculated)
String in Parallel	23418 (calculated)
Inverter	7806 (calculated)
Module Tilt and Azimuth Angle	Equal to latitude and 0 degree
Module	DSP80-290P (Jinhua dokio technology co. limited)
Inverter	Suntree LT 30000 HD
Battery	Lithium Ion: Nickel Manganese Cobalt Oxide (NMC)
Land	384.8 acres

IV. Simulation Study

A. P50/P90 Analysis

From the P50/P90 analysis (before and after optimization) by SAM, we found that BASHKHALI is the best place for implementing the CSP or PV power plant among four locations because the annual energy output, capacity factor and other metrics are more and LCOE is lower than other locations by running hourly simulations over a multi-year period (2000-2014).

B. Before Parameter Optimization

From the specified inputs for 200MW CSP and PV plant, the simulation results (before optimization) are shown in TABLE V.

TABLE V. Simulation Results of CSP and PV (Before Optimization)

Technology Name	Annual Energy (Year 1) kWh	Capacity Factor (%)	LCOE (real) (cents/ kWh)	Net Capital Cost ($)
PV 200MW (without battery)	184931600	11.1	6.08	357455456
PV 200MW (with battery)	182479728	11	6.16	357357824
Parabolic Trough (200MW)	262372528	15	12.48	939546944
Power Tower (200MW)	400598344	20	13.90	1303929984

V. Optimization of Parameters

A. CSP(Parabolic Trough and Power Tower) Technologies

In Parabolic Trough power plant and Power Tower Plant, varying the parameters namely solar multiple and thermal storage system, we can easily find the optimum condition for those power plants. we can see that the increase in solar multiple and thermal energy storage values, the capacity factor will be increased and LCOE will be decreased. So, for optimized output, we have selected the optimized values of SM and TES which is shown in TABLE VI.

TABLE VI. Parameters Optimization of CSP

Technology Name	Solar Multiple (SM)	Thermal Energy Storage (Hours)
Parabolic Trough	6.5	8
Power Tower	1.5	8

B. PV (Photovoltaic) Technology

From recent market prices, we have selected module, inverter, and battery that has better performance and reliability. As it is a mature technology, its price changing will be negligible.

The final simulation results are shown in TABLE VII.

TABLE VII. Simulation Results of CSP after Parameters Optimization

Technology Name	Annual Energy (Year 1) kWh	Capacity Factor (%)	LCOE (real) (cents/ kWh)	Net Capital Cost ($)
Parabolic Trough (200MW)	653338880	37.3	7.70	1572463872
Power Tower (200MW)	465325248	26.6	11.54	1042728576

VI. Study of Different Ratings Power Plants in Different Locations

For different power ratings in different locations for CSP, the changing parameters are designed gross output, land area, fixed annual cost, direct and indirect cost, and net capital cost. From the four locations, land cost is higher for BASHKHALI. Land cost for MAHESHKHALI is moderately high but relatively low for SANDWIP and even lower for VASHAN CHAR. But transportation cost and grid connection cost is highest for VASHAN CHAR, moderately high for SANDWIP and relatively lower for BASHKHALI and MAHESHKHALI. Module, string and inverter can be calculated for different ratings by applying same procedure which is done for 200MW solar PV. So, combining land cost, transportation cost and grid connection cost, a constant cost is taken. Considering this changing parameter, the outputs are shown in Fig. 4, 5, 6 and 7 respectively.

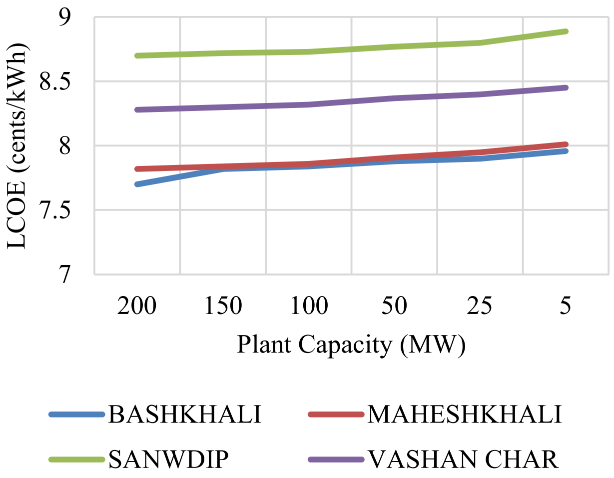

Fig. 4. Plant capacity vs. LCOE for the Parabolic Trough.

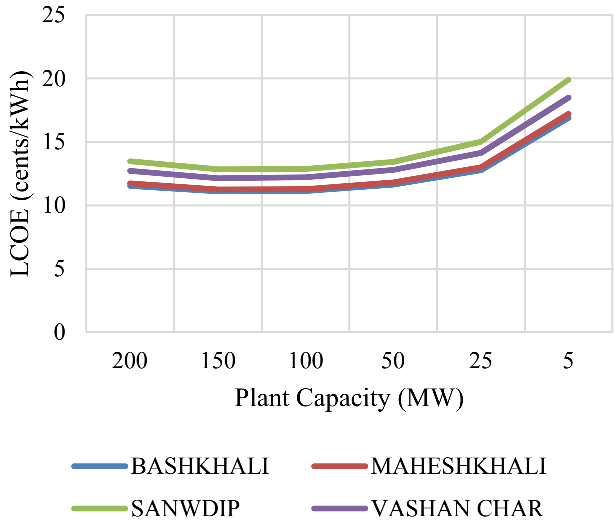

Fig. 5. Plant capacity vs. LCOE for Power Tower.

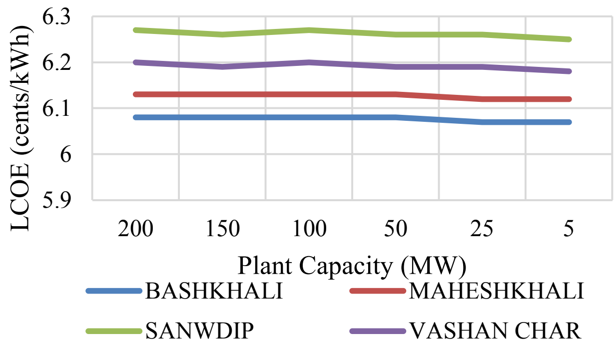

Fig. 6. Plant capacity vs. LCOE for PV without battery.

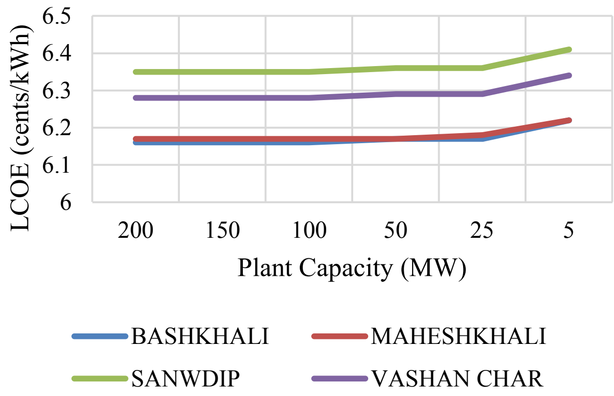

Fig. 7. Plant capacity vs. LCOE for PV with battery.

VII. Land Requirement for Different Ratings Solar Power Plant

The land is the most important raw material for implementing CSP or PV power plant. Land requirements for the different ratings solar power plant are shown in Fig. 8.

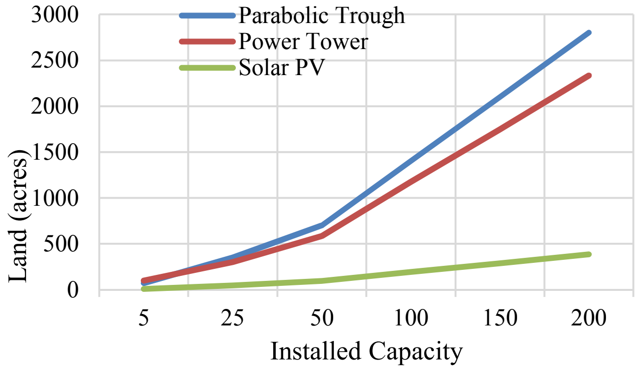

Fig. 8. Land Requirement for Different Ratings Solar Power Plant.

VIII. Results

A. Before Optimization

From Table V. we can see that from a 200MW plant, for annual energy generation of Power Tower is higher. But considering the LCOE, Solar PV is more preferable.

B. After Optimization

For parabolic trough, Annual energy output increases from 262,372,528 kWh to 653,338,880 kWh and Capacity factor increases from 15% to 37.3%. LCOE is reduced from 12.48 cents/kWh to 7.70 cents/kWh, considering the Table V and Table VII.

For power tower, Annual energy output increases from 400,598,344kWh to 465,325,248 kWh and Capacity factor increases from 20% to 26.6%. LCOE is reduced from 13.90 cents/kWh to 11.54 cents/kWh, considering the Table V and Table VII.

C. Different Rating Power Plants in Different Locations

We can see that BASHKHALI is a more suitable place for implementing Parabolic Trough Power Plant, Power Tower and PV (with battery and without battery) because annual energy generation and capacity factor are higher than other places which are shown in Fig. 4, 5, 6 and 7 respectively.

D. LCOE Projection Until 2050

From Fig. 9, we find that PV technology cost is lower than CSP. Behind this, one reason is that PV is more mature. We can also see that CSP will be more affordable in future.

E. Land Requirement

From Fig. 8, we see that for Parabolic Trough and Power Tower land requirement is 7-8 times or 5-6 times more than Solar PV. In Bangladesh, this huge land is the main problem as it is a densely populated country.

F. Comparison of the Analytical Results

Overall summary of optimized inputs and simulation results are shown in TABLE XI. From TABLE XI, we can see that PV is the best case for implementing power plant in Bangladesh.

TABLE XI. Summary of Optimized Inputs and Simulation Results

Technology Name	LCOE (cents/kWh)	Capacity Factor (%)	Land (acres)
PV 200MW (without battery)	6.08	11.1	Very much lower than parabolic trough and power tower.
PV 200MW (with battery)	6.16	11	
Parabolic Trough (200MW)	7.70	37.3	7-8 times higher than PV and also higher than power tower.
Power Tower (200MW)	11.54	26.6	5-6 times higher than PV but lower than parabolic trough.

IX. Conclusions

The operation of CSP and grid connected Solar PV plant has been shown in this study through comprehensive literature review. The results from the simulation suggest that Bangladesh is feasible for CSP and Solar PV power plant. Several simulations were done for different plant capacity in the selected locations. The results show that output energy and LCOE is almost same in BASHKHALI and MAHESHKHALI. Simulation results before and after optimization suggest that BASHKHALI is better for CSP and Solar PV plant. The P50/P90 analysis was done for the selected locations before and after optimization. This analysis also suggests that BASHKHALI is better for CSP and Solar PV. But as we have seen earlier, the output for BASHKHALI and MAHESHKHALI is almost the same. This little difference may be occurred due to small variation in their solar resource. From the whole study, it can be said that Solar PV plant is more suitable for Bangladesh. This is due to huge amount of land requirement for CSP technology compared with Solar PV. As, Bangladesh is a densely populated country, it will be very hard to find several thousand acres of land for implementing CSP plant. As a result, considering land utilization and low LCOE of Solar PV, installation of Solar PV plant should be the first option. However, if we consider the annual energy and capacity factor, CSP can be a good choice for implementing in Bangladesh.

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