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Cost analysis of concentrated solar power plant with thermal energy storage system in Bangladesh

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Abstract: Electricity is one of the most vital ingredients of socio-economic development of a developing country like Bangladesh. Sufficient supply of electricity is essential for attracting both domestic and foreign investment. Bangladesh electricity generation is heavily dependent on fossil fuel mostly natural gas. Due to lack of gas supply to the power plants, the Bangladesh government has ordered partial shut-down of natural gas stations in and around the capital to counter a growing power crisis. Furthermore, the price of liquid fuel is shooting up in a significant rate each year which is equally difficult for Bangladesh to purchase fuel from international vendors. It is therefore, necessary to switch to an alternative source of power generation which will be sustainable and environment friendly such as solar energy. Considering the electricity demand pattern, the use of molten-salt thermal energy storage (TES) system is proposed in this paper. The TES system will allow supplying power during the pick electricity demand period. With a detailed cost break down of solar thermal power plant along with a steam generated power plant and a liquid source power plant, this paper intends to establish the fact that, concentrated solar power (CSP) with TES is economically profitable in the long term for Bangladesh. This proposal may help the power system policy makers of Bangladesh Government to take solar thermal power into a careful consideration in order to incorporate this technology to the national grid.

Keywords: Thermal Energy Storage, Heliostats, Land Utilization, BRRI Dhan.

1. Introduction

Bangladesh has been suffering from acute power crisis over the last 7 years which created adverse impacts to the industrial and economic development of the country. Recent statistics by Bangladesh Power Development Board (BPDB) showed that, the peak power demand in the country is already about 6765 MW per day where the power generation is almost 4700MW per day [1] [2]. In full summer by the middle of next year it may grow to 7518MW per day [3].

Bangladesh is not obtaining satisfactory level of power generation due to lack of fuel supply, funds to set up extensive conventional power plants and import expensive fuel, and inefficient power policies to implement projects in time. It is time to evaluate the prospect of solar power as a remedy of the power crisis. Many recent developments have been on progress for solar system in the country to assist government in order to overcome critical power situation. But none of them has significant impact as the size of the power plants is small to meet the power requirement of a national grid. Therefore, Bangladesh has to think for a bigger solar power solution such as solar thermal power plants (STPPs). The STPPs are one of the most promising systems for generating electricity in any scenario of sustainable development [4]. At present, installation of these kinds of power plants is spreading widely. Considering the critical power crisis and power demand pattern, a power plant with energy storage system will be the most effective solution.

The capital city of Bangladesh has been experiencing four to five hours of load shedding each day. The condition of other cities and suburbs are even worst. The peak power demand is during 6pm to 11pm [2], where all the power generation plants come into operation. Lack of fossil fuel is the one of the significant reason of generating power under the required level. The current statistic of BPDB shows that lack of gas supply causes almost 1000 MW less power generation from the desired level. Moreover, at present other types of liquid fuels are very expensive to import. Therefore, the use of thermal energy storage system is economically feasible option for this energy crisis [6].

The system can hold the necessary energy to produce electricity up to 6 hours which can meet the power requirement during the peak demand period of the capital and major cities in Bangladesh [4],[5] Although the capital cost of setting

up a solar power plant with energy storage system would be high comparing to the conventional fuel powered generation plant under equal power output. However, considering the fact of zero fuel cost the former type of plant will be most economically benefited in the long run [7].

This paper also discusses the current power condition in Bangladesh followed by an explanation of the prospect of establishing CSP plant with TES. This is further discussed in association with a detailed cost break down and a general estimation of capital required for 20MW power. Finally, the setup cost for gas and liquid fuel powered generation plant is presented. Subsequently, some details about land utilization is given. A cost factor of CSP with TES has been analysed followed by a justification of the project at the end. This cost analysis had been performed based on the data collected from different sources such as Bangladesh Power Development Board (BPDB) and one commissioned CSP power plant by CSIRO in Australia. With through market survey on local companies associated with civil and electrical works, the research developed actual cost tables for installing different parts of the CSP plant with thermal energy storage system. This paper finally compared the total cost required for setting up three different types of power plants (CSP with TES, Steam Generation and Liquid Fuel Power Plant). The cost analysis shows that the capital cost of setting up a CSP plant with TES is relatively high comparing to other two kinds of power plant. However, in the long term CSP offers good solution in terms of cost effectiveness and environmental issues.

2. Current State of Power Supply in Bangladesh:

Present electricity growth in Bangladesh is 10 % of the 2010 Financial Year (FY) with average growth of 7 % since 1990 [2]. The generation capacity was 5936 MW by December 31, 2011 serving nearly 48.5 % of entire population of the country [12].

Total electricity generation capacity for the year of 2011 is given in table 1. It is worth noting that the available generation capacity is in the range of 4600 – 5000 MW considering the fact that, all power plants receive adequate fuel supply.

Table 1: Total Electricity Generation of Bangladesh [2].

SL	**Public Sector**		**Generation Capacity (MW)**
1	BPDB		2620
2	Ashuganj Power Station Company LTD.		6060
3	Electricity Generation Company of *Bangladesh*		255
	Subtotal		3481 (59%)
	Private Sector		
1	IPPs		1271
2	SIPPs (BPDB)		99
3	SIPPs (REB)		226
4	15 YR. Rental		168
5	3/5 YR. Rental		441
6	Quick Rental		250
	Subtotal		2455 (41%)
	Total		5936

2.1 Demand Supply Situation

In 2010, maximum electricity generation was 4000 – 4600 MW with the possible generation capacity- 5936 MW against the demand of 6454 MW. The highest electricity was achieved on 20 August 2010 with 4699 MW giving almost 2000MW shortage each day [2],[3]. Gas shortage causes 500 - 700 MW less power generation which is the prime obstacle to achieve the maximum generation capacity.

2.2 Average Peak Power Generation

Figure 1 shows total power generation from 2007 to 2010. The generation had been constantly increasing each year up to 2009. However, as mentioned above due to lack of sufficient gas supply the electricity generation significantly dropped in the year 2010.

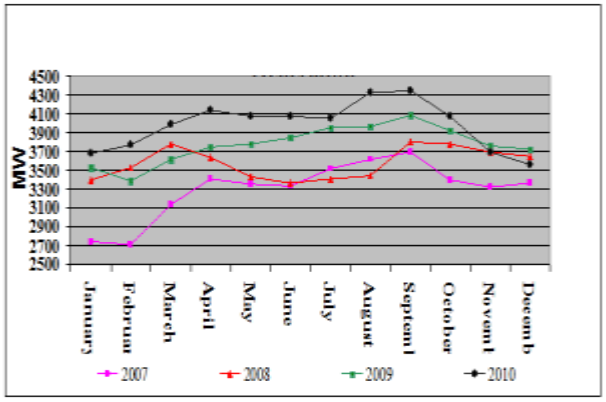

Figure 1: Improvement of Electricity Generation [2].

2.3 Energy Generation by Fuel Type:

The rest of the electricity comes from furnace Oil (FO) 3%, diesel1.76%, Hydro, 2.5% and coal 3.53%. The dependency on the Natural gas for generating electricity is the main concern where the gas supply is limited and gas shortages has a significant impact of not achieving expected generation capacity.

Figure 2 shows that the natural gas contributes 89.2% of the electricity generation [2].

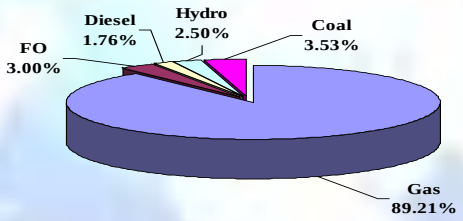

Figure 2: Fuel Used for Electricity Generation [2].

3. Prospect of CSP with TES System in Bangladesh

Bangladesh is situated between 20.30-26.38 degree north latitude and 88.04-92.44 degree east which is an ideal location for solar energy utilization [8]. From research conducted from several institutions it has been established that there is a good prospect of harnessing solar power in Bangladesh. Solar radiation varies between 4 and 6.5 $KWh/m^{-2}day^{-1}$. Maximum amount of radiation is available in the month of March- April and minimum in December- January. Daily average solar radiation varies between 4 and 6.5 KWh/m^2.

Distance from the equatorial line: Places near the equatorial line get sunlight almost perpendicularly, which means sunlight travels less distance to reach these places [9]. As we move towards the north and the south poles sunlight falls at a larger angle and travels longer distance that lead to lower intensity of sunlight. Bangladesh is very close (23.50 North) to the equatorial line. The proximity of Bangladesh to the equatorial line benefits in two different ways:

(1) The variation of the length of the day from winter to summer seasons is smaller than most of the other countries, consequently, for a commercial solar plant it would be easier to calculate the average production capacity per day over the whole year.

(2) Sunlight falls almost perpendicularly on our land for a longer period during the year, which provides sunlight with higher intensity for higher number of days in a year.

Concentrating solar power plants with thermal storage system can be economically benefited for the developing county like Bangladesh because of its low operating cost [1], [13]. This sort of power plants is not adversely affected from fuel price fluctuation [3]. Moreover, concentrated solar power plants can offer some social benefit to the country generating technical, non-technical, skilled and semiskilled employment during plant erection and commercial operation. There is no hidden social cost in the form of environmental pollution, addition of social services or other resulting economic effects. Land area used for erection of heliostats can be used also for cultivation of crops depending on proper design. Concentrating solar power plants also create two and half times as many skilled jobs as any traditional plant.

4. Initial Plant Specification

The proposed concentrated solar power plant with thermal energy storage system specification is given in table 2.In this paper, the cost break down of each component is given. From the detailed cost break down the cumulative cost of the project is interpreted.

Table 2: Plant Specification [14].

Plant capacity	20MW
Storage	6Hours
Working fluid	HTF (60% NaNO3, 40% KNO3) Hot temperature: 574 °C and Cold temperature: 290 °C
Receiver	Cylindrical, 24 panels, Height: 18.49m, Diameter: 11.56 m Receiver Area: 671.5 m2
Tower	205.56 m
Power block	Turbo-generator: 20 MWe Turbine steam conditions: 539 °C / 16.5 MPa
Cooling System	Dry cooled Air cooled condenser
Land area	213966 sq. M

4.1. Cost Estimation of TES:

As CSP with energy storage system had not been established in Bangladesh before, it is difficult to find reliable cost information for such plants. Considering the fact that this sort of project is high capital intensive, it is therefore, predictable that the capital cost will be relatively higher than any other traditional power plant like liquid fuel or gas generated power block. It is important to note though that the costs of first-of-a-kind plants are often significantly higher than subsequent plants as these plants involve the one-off establishment of infrastructure [14], [15]. Future costs will vary based on local factors, e.g., taxes, labour costs, availability of materials in local market etc. Bangladesh government impose zero tax to the power generation plant establishment and the local labour cost is relatively cheaper than in any other country where CSP with energy storage system have been in place. This country produces almost all materials except very few highly technical instruments which significantly reduce the capital cost. Although it economically benefits to set up a large CSP plant than a small one considering the fact that this sort of project is a first of its kind in Bangladesh this paper intends to propose a 20MW power plant with a scope of extending the power plant up to 100 MW of capacity if required.
Depending on the particular equipment, the following methods are used to estimate its fabrication and installation costs. In most cases an alternative method was used for verification. The methods include:

Cost estimation through local market survey: Assuming that most of the infrastructural materials will be collected from local market and the prices of the materials are obtained from local suppliers. Examples include steel, cement/ concrete, glass, metal structure, labour etc.

Data collection from similar kind of projects overseas: As this sort of project is a first of its kind in Bangladesh, it is important to collect some cost information from various similar projects in different countries.

International tender call: The potential lower cost can be obtained for certain highly technical equipments that will be purchased from overseas suppliers.

4.2 Component Costing

There are four major areas in setting up a solar power plant with thermal energy storage systems. First, it is difficult to obtain practical financial data from local reliable sources like Bangladesh Power Development Board (BPDB) since this sort of power is new of its kind. However, some financial figures like civil works on tower system can be estimated form local market survey and mechanical works in power block can be obtained from other similar kind of power plants.

4.2.1 Solar Field

A 20MW CSP plant requires approximately 213966 m^2 of solar fields, accommodating 1400 heliostats [10]. The heliostat mirrors are designed and fabricated by glass which is adhered to on top of the steel structure frame onto concrete foundations. Each heliostat will require motors and tracking systems and field wiring to control and track the sun and concentrating the solar radiation on the receiver.

Costing was based on a combination of literature review and current local market survey for the material used for manufacturing. Number of studies were reviewed for heliostat pricing in $/$m^2$ and material quantities per heliostat. Materials include kilograms of glass, ton of steel and cubic meter of concrete as well as actuators and field wiring From the local market price and manufacturing infrastructure it is estimated that heliostat fabrication and erection cost will be around \$87/ m^2 in Bangladesh [14][15].

4.2.2 Receiver

The receiver is assumed to be with 24 adjacent panels arranged around the perimeter of a 12.44 m diameter tower structure [10],[14]. Each panel is 19.91 m high and comprises of 40 individual 0.04 m OD tube joining to a common header at either end. Costing the receiver assumed two pipe sizes, 40 mm for the parallel panel runs and 150 mm at the headers and inter-panel connections to maintain the flow rate. All components are to be fashioned from commercially available schedule 5, 316 Stainless Steel tubing. An average labour cost of \$10/hr per person. A tentative cost break down of the receiver system is given in the table 3.

Table 3: Estimated cost for receiver [14]

Panels	
Total length (OD 40mm)	19453
Unit Cost	\$19/m
Time for labour	.41hr/m
Time for labour (Joining to Header)	1 hr/tube
Sub total	449,764
Headers and Inter-panel Connection	
Total Length (OD 150mm)	142
Cost	\$61.49/m
Time for Labour	0.89 hr/m
Subtotal	9,996
Design, Fabrication and Installation	
Engineering Design	168450
Transportation to Site	65789
Assembly Labour	131578
Miscellaneous	167115
Total	992,692

4.2.3 Tower

For storage system the tower height is suggested to be 205 metre. The estimated cost depends on civil work and structural design [17]. The required cement and other materials will be procured from local market. The cost of tower construction varies from one construction company to another. Considering the satisfactory level of the construction quality, the lowest price will be encouraged thorough tenders. From local market pricing index an approximate cost can be estimated which is given in the table 5.

4.2.4 Molten Salt Thermal Storage System:

Depending on the specific storage and operational requirements, a concentrated solar power plant requires at least two Heat Transfer Fluid (HTF) tank. Each tank will store cold and hot molten salt separately [17][21]. Both the hot and cold tanks each with a capacity of 7.5 ML have a diameter of 21.92 m and height of 20 m [19]. Table 4 outlines the cost break down for the tanks and tank foundations. The Hot Tank (HT) requires an additional insulating fire bricklayer. Solar Salt (60:40: Na:K Nitrate) Costs, $0.49 per Kg or $5.8 per kWh.

Table 4: Estimated cost for thermal storage system [15].

Materials	Quantity	Value	Unit	Cost($)
Calcium Silicate	3600 M^3	90	$/ m^3	324000
Steel	1414.874 Tonn	809	$/Kg	1130062
Concrete	686 M^3	22.5	$/ m^3	15435
Foam Glass Volume	241 M^3	450	$/ m^3	108450
Refractory brick	91 M^3	250	$/ m^3	22750
Fire brick	5904 Bricks	0.40	$/brick	2362
Insulation concrete	109 M^3	24	$/$m^3$	2616
Steel Slip Plate	35.53 Tonn	809	$/Tonn	28752
Labour	800 hr	28	$/hr	22400
Total				1,656827

4.2.5 Power Block

The power block design consists of a conventional steam cycle. Steam is raised and superheated by the heat transfer fluid (HTF) via a number of shell and tube heat exchangers. The steam drives a single reheat turbine with air cooled condenser (ACC) [10],[14]. The power block establishment cost is obtained from other steam turbine power plants from various project as this type of technology had been previously used in Bangladesh.

4.3 Approximate Capital Cost for Solar Power Plant with TES System

With the methodology given above an estimated cost of a 20MW CSP plant with thermal storage system is given in table 5:

Table 5: Cost Estimation of 20MW CSP with TES Power Plant [2][14]

Site Preparation	$30/KW	$600,000
Solar Field & Heliostat	$ 884/KW	$17,680,000
Tower	$29/KW	$580,000
Receiver	$50/KW	$1,000,000
Molten Salt	$82/KW	$1,640,000
Steam Generation and Turbine System	$152/KW	$3,040,000
Heat Recovery	$95/KW	$1,900,000
Master Control	$55/KW	$1,100,000
Electrical	$70/KW	$1,400,000
Spare (8%)		$2,586,000
Total		$31,526,000
Operational and Management/year (Fixed + labour +material+ Financial)		$2,210,526

5. Cost Set Up of Liquid Fuel Power Plant

An elaborate cost breakdown is not available for a liquid fueled power plant whilest data collected from Bangladesh Power Development Board through private communication by the authors show approximately $790 per kW is required to bring a plant into full operational capability. which is relatively lower price in terms of setting up cost for a plant with 20MW capacity. Most of the fuels are imported to the system. For a 20MW power plant the daily consumption of the fuel required with 80% plant factor is almost 80 tonnes. And the current market price of the fuel is $ 0.66/litre. An overall estimated cost is given in table 6.

Table 6: Total Cost of 20 MW Liquied Fuel Powered Electricity Generation System [2]

Set up cost	$ 790/KW	$15,800,000
Fuel cost/year	$0.66/Litter	$19,008,000
Operational and Management/year (Fixed + Variable + Financial)		$ 1,595,790

6. Cost Set Up of Steam Generation Plant

Table 7: Total Cost of 70MW Steam Generation System [2],[16]

Mechanical system	$897/KW	$62,781,251
Electrical system	$130/KW	$9,075,518
Instrumentation and control	$92/KW	$6,404,065
Civil work	$461/KW	$32,296,414
Services	$289/KW	$20,229,328
Contractual Spare parts, tools and consumable	$242/KW	$17,000,000
Fuel cost/year	$0.395/ m^3	$9,198,065
Total		$147,786,576
Operational and Management/year (Fixed + Variable + Financial)		$ 3,815,790

Table 7 shows the 70MW gas powered steam generation power plant of Rural Power Company Limited (RPCL). The total cost indicates that the establishment of such type of steam generation power plant is much higher than the liquid fuel powered one. However the unit price of gas is very low which is at present around $0.395/ m^3. This is the reason why the government is inspired to spend too much currency on setting up gas powered generation plant.

7. Land Utilization

Although land used for solar thermal power plant is considerably higher than conventional fossil fuel based thermal power plan, this 20MW thermal power project adopt different land utilization schemes from other solar thermal power plants [8]. A 20% of total required land will be utilized to construct building of turbine, generator, control room, administration office, solar tower approach, internal road and other machineries. Rest of the 80% land will be used for installing of heliostats as well as crops cultivation and fisheries purpose.

Heliostats will be installed at safe height from the ground level so that paddies like Amon or buro rice can be cultivated. Because heliostats will be always moving during day time, so there will be always sunny areas which will facilitate the cultivation of crops. This land utilization scheme will allow the project to obtain multipurpose income generating sources by generating electricity and crops, fish or shrimp cultivation and obtain the turnover greater than any other traditional power plants.

8. Cost Analysis

The cost break down shows that although the capital cost of $31,526,000 for solar power plant with TES is higher than the liquid fuel power plant but lower than gas powered one. The data in table 8 shows that the running cost of CSP is significantly lower than the liquid fuel powered generation system. Comparing with the gas plant, the CSP is relatively higher in terms of yearly operational cost. It is clearly understood from the same table that, the gas plant is very

economically viable in the long term as compared to the liquid fuel power plant. Although the capital cost of gas generated power plant is $2,112.31 per KW which is significantly higher than setting up a liquid fuel power plant, but with a life span of 20 years the liquid fuel will cost approximately $380,016,000 which is more than double than the natural gas around $184,000,000.

Table 8: Cost comparison of three different power plants

	CSP with TES	Gas	Liquid Fuel
Capital Cost/kW	$1,576.3	$2,111.24	$790
Fuel cost/kW	--	$460/Year	$950.4/Year
Running Cost/kW	$110.5/ Year	$54.5/ Year	$79.8/ Year

This estimation had been done with current market fuel prices. Considering the constant increase of fuel prices all over the world, this price will invariably shoot up in significant amount. At the same time constant natural gas supply to the generation plant also remains uncertain in the future. On the other hand, a solar power plant is usually designed for 30 years and does not require any fuel supply expect for the molten salt based thermal storage system [11]. The running cost of a CSP plant is almost double than the gas power plant, but the zero fuel price will compensate this short coming of such type of electricity generation plant and reduce a significant amount of expenditure in the long run.

Proper land utilization will allow the power plant to obtain some extra revenue each year. In this case from the required plant land area of 27.08 hectares as much as 80% of it can be utilized for crop cultivation. A research conducted by Bangladesh Rice Research Institute had invented new hybrid paddy 'BRRI Dhan 28' and 'BRRI Dhan 55' with growth duration of 145 days and can harvest 7.0-7.5 tonnes crop per hectare. Other types of paddy can be cultivated on the same land for the rest of the year giving 3.0-3.5 tonne/hectare each time. Therefore, this land can produce approximately 216.7-238.4 tonne/year. The current market price of the rice in Bangladesh is $436/tonne. Thus, approximately $103,943 could be achieved from land cultivation which will add in to the plant total [18].

9. Justification

The natural gas has been considered the major source of electricity at present days in Bangladesh. Almost 89% of electricity has been generated from natural gas. Current low market price and natural storage of the natural gas are the prime reasons of the dependency on this particular power source. But the fact is that, the gas powered electricity generation plants are not meeting the maximum plant capacity level due to insufficient supply of gas. It is to be considered with optimum attention that the gas supply is limited and the amount of naturally reserved gas reducing day by day. Bangladesh has to switch to alternative source of power generation eventually giving less emphasis to natural gas-mode.

Considering the constant rise of the fuel prices all over the world, Bangladesh Government is intending to stop all subsidies from the fuel which will shoot up the fuel price up to $1.02 per litter. Therefore, it is time to find an alternative solution of harvesting electricity other than fossil fuel source. The urge of being green indicates the CSP to be the most effective alternative source of generating power. Capital cost of solar power plant with TES is much higher than any other fossil fuel powered generation plant, but with a proper cost reduction study this cost of reduced [7]. From different cost reduction studies it had been found that significant reductions in cost were possible through a combination of mass manufacturing and technological improvement and innovation [14].

Studying the electricity demand pattern in Bangladesh, it is evident that the pick demand period is during 6pm to 11pm every day (DPDC 2011). The solar power plant with energy storage system is the best solution at this moment for meeting the power demand as the proposed project will provide 6 hours of energy storage [20]. Therefore, the solar plant can go on to operation after dusk with maximum capacity.

The plant will use optimum recycling materials for the construction like steel, glass etc which can be reused after decommissioning the power plant. This approach will allow reducing the carbon footprint by emitting less carbon to the environment. Emissions caused mainly during the construction phase and rest of the operational period the plant will cause very low pollution to the environment.

Conclusion

The purpose of establishing 20MW concentrated solar power (CSP) plant integrated with thermal energy storage (TES) system in Bangladesh is to secure power supply in pick electricity demand period with lowest CO_2 emissions [7][8]. This paper has analysed the tentative cost required for solar power plant with thermal storage system in Bangladesh. All estimated component quantity and cost had been collected from local market evaluation and some similar type of commissioned solar power plants worldwide. The study had shown that, the capital cost of CSP with thermal storage system is almost double than that for liquid fuel fired power plant but considerably lower than that for gas fired electricity generation. As far as the capital cost of setting up a power plant is concerned, the liquid fuel power generation plant would receive the first preference. Considering the increased fuel price worldwide and total quantity required for a power plant with similar capacity however, compelled the government of Bangladesh to evaluate the possibility of generating electricity from different source. The gas has been the top most preferred fuel for power generation for many years for its availability and low cost in the country. Recent crisis of natural gas has been causing many gas powered electricity generation plant to remain inactive. Therefore, this paper proposed to establish a solar power plant in Bangladesh for the first time. The CSP can operate with optimum efficiency if the plant is integrated with thermal energy storage system. With the help of TES the power plant can offer electricity supply during evening time when the power demand is high. The comparison of economic feasibility of solar power plant with the TES-based system with traditional fossil fuel generated power plant in Bangladesh had indicated the fact that, the CSP with TES can be considered as an alternative power source in order to encounter acute power crisis in Bangladesh.

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