Design of solar parabolic trough plant for a village in Rajasthan

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Abstract-*To fulfill the need of electrical energy and also cut down the dependency on state distribution company for power supply, a solar parabolic trough power plant is proposed for village Mansarkheri situated in district Jaipur. Electrical energy demand of the village has been found by surveying the village and also from electricity Distribution Company. Energy requirement is found to be 584.60 MWh/annum and 557.12 MWh/annum according to survey data and bill data respectively for year 2014. Solar parabolic trough power plant is designed to fulfill the energy need of year 2015, 2019 and 2024. Electrical energy demand and capital cost for year 2019 and 2024 has been achieved by linear regression based forecasting. Energy demand for year 2015, 2019 and 2024 have been calculated as 638.25 MWh/annum, 821.27 MWh/annum and 1072.01 MWh/annum respectively. Solar parabolic trough power plant capacity is calculated as 312.61 kW 451.24 kW 641.88 kW for year 2015, 2019 and 2024 respectively. According to these required capacities, the other designed parameters of solar parabolic trough plant are calculated.*

Key words: Solar parabolic trough plant, Survey, Electrical energy demand

1. INTRODUCTION

In Bassi sub division of Jaipur district, Mansarkheri village is situated at (latitude 26°83'N, longitude 76°05'E**,** altitude 351 m. Population of the village is 3662 and total number of households are 513 according to census 2011 data. Need of electricity in the village is both for household purpose and agricultural purpose for which the villagers completely depends on local electricity distribution company. The tariff of the electricity is the major issue for the villagers according to their opinion. Therefore there is need for a economical and sustainable energy source in order to supply desired power demand.

Chandel et al. [1] proposed one on-site solar photovoltaic power plant and one off site solar photovoltaic power plant in order to provide required electricity to the garment zone located in Jaipur in Rajasthan state. The internal rate of return (IRR), net present value (NPV) at 10% discount rate, simple pay-back period, discounted pay-back period at 10% discount rate and Levelized cost of energy at 10% discount rate are 11.88%, 119.52 million INR, 7.73 years, 15.53 years and 14.94 Rs. Per kWh for on-site power plant and 15.10%, 249.78 million INR, 6.19 years, 10.14 years and 11.40 Rs. Per kWh for off-site power plant. **Agrawal et al. [2]]** proposed one on-site solar parabolic trough power plant and one off site solar parabolic trough power plant in order to provide required electricity to the garment zone located in Jaipur in Rajasthan state. The internal rate of return (IRR), net present value (NPV) at 10% discount rate, simple pay-back period, discounted pay-back period at 10% discount rate and Levelized cost of energy at 10% discount rate are 19.21%, 372.77 million INR, 5 years, 7 years 4 months and 9.41 Rs. Per kWh for on-site power plant and 27.85%, 550.55 million INR, 3 years 6 months, 4 years 7 months and 6.89 Rs. Per kWh for off-site power plant. **Kobayakawa and Kandpa [3]** proposed a methodology in order to maintain balance between financial viability of any rural electrification project and the affordability of the electricity generated by the project by considering tariff as an important parameter. **Hrayshat [4]** designed an optimal hybrid system involving photovoltaic, diesel generator and battery storage system which is not connected to grid (off grid) for the purpose of providing electricity to a house located in remote area of Jordanian territory. It is observed that when the electricity is generated by using this hybrid system the operating hours of diesel generator system are decreased by 19.3% and in turn it reduced the consumption of diesel by 18.5% as compared to the case when electricity is generated by only diesel generator system. **Poullikkas [5]** showed his study on the feasibility analytics of a solar parabolic trough based solar thermal technology installation for the purpose of generation of electricity in the selected location of Mediterranean region. He concluded his study that solar parabolic trough power plants are economical as well as profitable in certain conditions. **Muneeret al. [6]** suggested that future energy security can be confirmed by using electricity generated by solar photovoltaic facilities. Six important cities of India i.e. Mumbai, Delhi, Chennai, Kolkata, Trivandrum and Jodhpur are selected in order to exercise modular approach on these for fulfillment of energy demand of those cities in 2025. **Ishan and Pallav [7]** evaluated the solar power generation based on concentrating technology (CSP), technically as well as financially in India. They concluded that CSP based power generation facilities are financial feasible for selected part of India like north-western part especially Rajasthan and Gujarat states. **Celik [8]** evaluated a small scale hybrid type of energy generation facility which involved photovoltaic system and wind energy system, techno-economically. They found that hybrid combination of photovoltaic system and wind system giving better performance results as compared with single system generation facility either of photovoltaic or wind system.

2. ENERGY DEMAND ESTIMATION

Electrical energy demand of the village for year 2014 is found by surveying the village by a quessionaire template and also from bill data provided by electricity Distribution Company. Consolidated electrical energy consumption data both from survey and bill are tabulated in table-1.

Table-1: Consolidated electricity consumption data of Mansarkheri village for year 2014

S.No.	Particulars	Bill data	Survey data
1	Energy consumption of village in MWh/annum	584.60	557.12
2	Energy consumption of family in kWh/annum	1139.58	1086
3	Per capita Energy consumption in kWh/annum	159.64	152.13
4	Energy consumption of village in MWh/month	48.72	46.43
5	Energy consumption of family in kWh/month	94.97	90.50
6	Per capita Energy consumption in kWh/month	13.30	12.68
7	Average power in Kw/month	228.81	218.06

3. Population and Energy Consumption Forecasting

Total electrical energy consumption can be found by multiplying per capita energy consumption with population of the village. Therefore per capita electrical energy consumption and population are forecasted to obtain per capita energy consumption and population in year 2015, 2019 and 2024. Population forecasting and per capita energy consumption forecasting are tabulated in table-2 and table-3 respectively. Table-4 is showing the bi-monthly electricity consumption data of village Mansarkheri from year 2010 to 2024.

Table-4: Power requirements in kW of village Mansarkheri for 2010-2024

Year	Feb	Apr	Jun	Aug	Oct	Dec
2010	139.10	158.43	181.64	219.56	128.98	186.09
2011	181.38	176.99	146.25	180.71	184.39	152.23
2012	151.78	134.33	216.79	222.44	288.24	258.11
2013	212.60	244.40	258.38	226.29	224.39	186.18
2014	239.98	144.13	259.87	192.03	261.53	237.71
2015	256.64	183.80	295.30	205.11	312.61	246.32
2019	360.99	200.68	412.34	199.36	451.24	307.30
2024	504.33	222.78	574.86	189.79	641.88	390.33

4. SOLAR PARABOLIC TROUGH PLANT COMPONENTS

4.1 Receiver tube

Receiver tube is the basic component of the solar parabolic trough power plant. The schematic diagram of receiver tube is shown in Figure-1 and the specifications of the receiver tube are tabulated in Table-5.

Table -5: Receiver tube specifications

S. No.	Parameters	Value
1	Receiver type	SCHOOT PTR™80
2	Absorber tube diameter	80 mm
3	Glass envelope diameter	125 mm
4	Receiver length	4.72 m

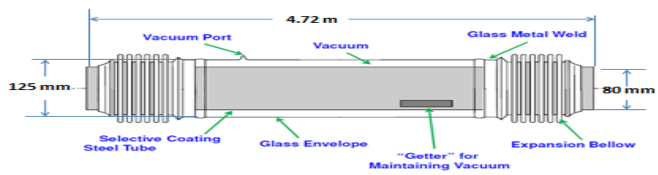

Figure -1: Receiver tube of solar collector

4.2 Solar collector elements (SCE)

1 SCE = 3 Receiver tubes + 1 Reflector mirror [2]

Dimensions of solar collector element are tabulated in Table-6 and geometry of the solar collector element is shown in Figure-2.

Table -4.2: Solar collector element specifications

S. No.	Parameters	Value
1	Solar collector element length (m)	14
2	Solar collector element width (m)	6
3	Solar collector element aperture area (m^2)	82
4	Mirror area to aperture area ratio	1.12
5	Focal length (m)	1.71
6	Rim angle (degree)	82.5
7	Geometric concentration	75/ 1

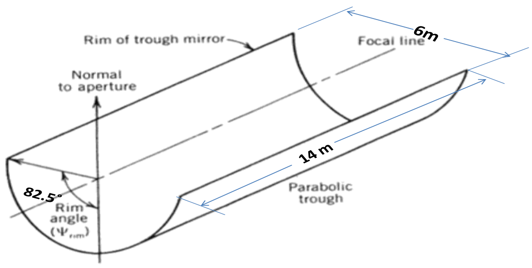

Figure-2: Geometry of solar collector element

Table-2: Population forecasting [9]

Year	1951	1961	1971	1981	1991	2001	2011	2015	2019	2024
Population	891	985	1233	1525	2177	2834	3662	3474	3659	3891

Table-3: Per capita energy consumption in kWh of village Mansarkheri

Year	Feb	Apr	Jun	Aug	Oct	Dec	Annual per capita (kWh)	Population	Annual Consumption(MWh)
2010	17.72	20.86	23.92	29.38	16.98	24.50	133.37	3243	432.48
2011	22.78	22.98	18.99	23.85	23.94	19.76	132.29	3289	435.10
2012	18.79	17.20	27.75	28.94	36.90	33.04	162.64	3335	542.44
2013	25.97	30.86	32.63	29.04	28.33	23.51	170.34	3382	576.01
2014	28.91	17.95	32.37	24.31	32.58	29.61	165.74	3428	568.14
2015	30.51	22.59	36.29	25.62	38.42	30.27	183.71	3474	638.25
2019	40.74	23.42	48.12	23.64	52.66	35.86	224.44	3659	821.27
2024	53.54	24.45	63.09	21.17	70.45	42.84	275.54	3891	1072.01

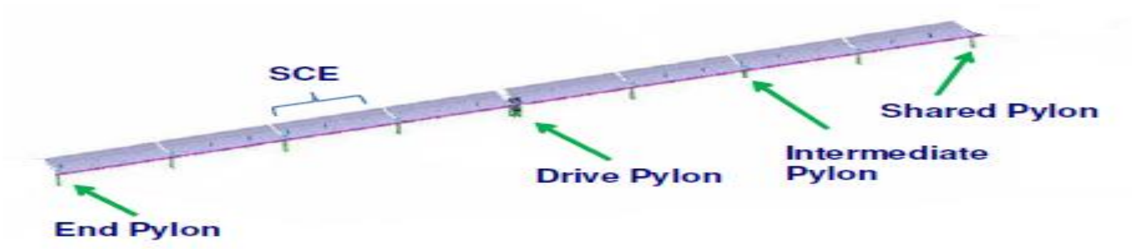

Figure-3: Solar collector assembly

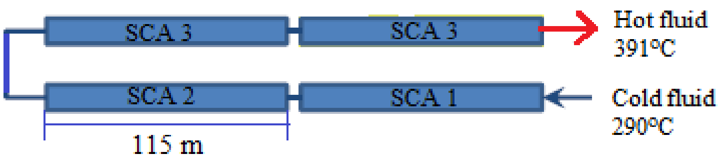

Figure-4: Solar collector assembly loop

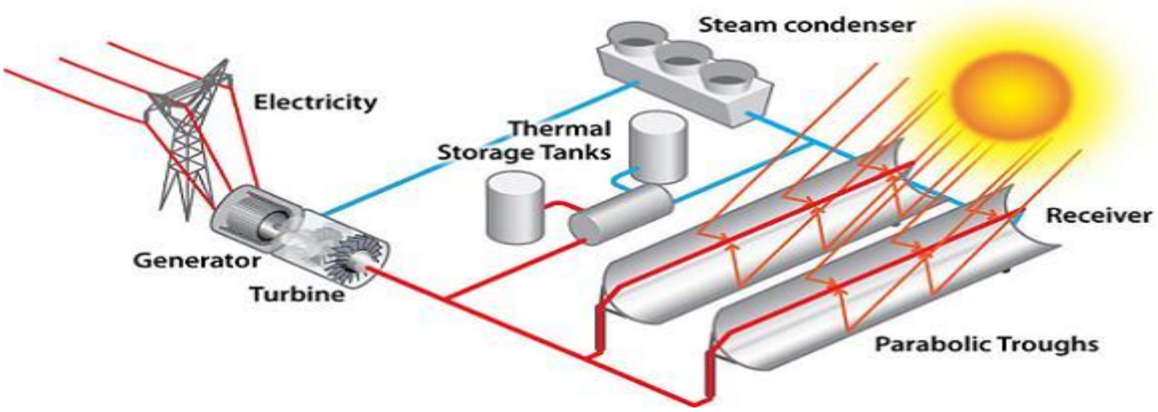

Figure-5: Schematic diagram of solar parabolic trough power plant

4.3 Solar collector assembly (SCA)

1SCA = 8 SCE +1 Drive Pylon + 6 Intermediate Pylon + 2 Shared/End Pylon [2].

The specifications of solar collector assembly are shown in Table-7 and the schematic diagram of solar collector assembly is shown in Figure-3.

Table-7: Solar collector assembly specifications

S. No.	Parameters	Value
1	Solar collector assembly length	115 m
2	Net aperture area	656 m^2
3	Total mirror area	750 m^2

4.4 Solar collector assembly loop

1 Solar collector assembly loop = 4 Solar collector assembly [2]
Aperture area of one loop =
4 x Aperture area of one Solar collector assembly

Aperture area of one loop = 4 x 656 = 2624 m^2

$$\text{Number of loop required} = \frac{\text{solar collector area}}{\text{area of one loop}}$$

Number of solar collector assemblies required = 4 ×Number of loop required

Number of solar collector elements required =

Number of solar collector assemblies required X Number of loop required

Number of Receiver tubes required =

Number of solar collector elements required X Number of loop required

The schematic diagram of solar collector assembly loop is shown in Figure-4. The technical specifications of selected turbine, steam generator, pre-heater, re-heater are tabulated in table-8, table-9 and table-10 respectively.

Table-8: Siemens SST-050 Turbine specifications

S.No.	Particulars	SST-050
1	Power output	750 kW
2	Inlet pressure	Up to 101 bar(a)/1,465 psi
3	Inlet temperature	Up to 500 °C/930 °F
4	Speed	Acc. to driven machine
5	Exhaust pressure	Back pressure up to 11 bar(a)/160 psi

Table-9: Technical specifications of the steam generator and preheater

S. No.	Parameters	Values
1	Type of the steam generator	Tube-in-shall
2	Temperature of the HTF at inlet of steam generator, °C	390
3	Temperature of the HTF at outlet of steam preheater, °C	281
4	Steam pressure at desired output, bar (abs)	103
5	Steam temperature at steam generator outlet, °C	375
6	Water temperature at preheater inlet, °C	105
7	Flow of steam at desired output, kg/sec	10

Table-10: Technical specifications of Re-heater

S. No.	Parameters	Values
1	Type of the re-heater	Tube-in-shall
2	Temperature of the HTF at inlet of re-heater, °C	390
3	Temperature of the HTF at outlet of re-heater, °C	240
4	Steam pressure at desired output, bar (abs)	18.5
5	Steam temperature at re-heater outlet, °C	371
6	Steam temperature at re-heater inlet, °C	220
7	Flow of steam at desired output, kg/sec	10

5. SOLAR PARABOLIC TROUGH PLANT DESIGN FOR YEAR 2015

In this section solar photovoltaic power plant is designed for village Mansarkheri with the considerations of 2015 year energy requirement.

5.1 Rating of SPT power plant

Solar parabolic trough power plant is designed in the accordance of the maximum demand occurring at load side. The peak power demand at load side must be taken in to consideration for estimating the rating of solar parabolic trough power plant. The maximum demand of the village is 312.61 kW. Therefore Rating of SPT power plant = 312.61 kW

5.2 Solar collector area

Solar collector area of a solar parabolic trough plant is the function of required output power i.e. rating of the SPT power plant and the solar irradiance of the site selected.

Solar collector area=

$$\frac{\text{Required output power}}{\text{Solar intensity} \times \text{Overall efficiency of plant}}$$

Required output power = 312.61 kW

Solar intensity at Jaipur (Rajasthan) = 617 W/m²

Overall efficiency of plant = 21.15%

Solar collector area = $\frac{312.61 \times 1000}{617 \times 0.2115}$

= 2395.56 m2 ~ 3000 m²

5.3 Solar field elements

Number of loop required = $\frac{\text{solar collector area}}{\text{area of one loop}}$

Area of one loop = 2624 m²

Number of loop required = $\frac{3000}{2624}$ = 1.14 ~ 2 loops

Number of solar collector assemblies required = 8 × 2 = 16 SCA

Number of solar collector elements required = 16 X 8 =128 SCE

Number of Receiver tubes required = 128 X 3= 384 Receiver tubes

5.4 Land requirement

Length of one SCA = 115 m

Length of one SCA loop = 2 x Length of one SCA

= 2 x 115 =230 m

Length of the field = Length of one SCA loop = 230 m

Width of one SCA = 6 m

Width of one SCA loop =

(2 x Width of one SCA) + Separation between two SCAs

Separation between two SCAs = 12 m

Width of one SCA loop = (2 x 6) + 12 = 24 m

Width of the field =

(4 x Width of one SCA) + (3 x Separation between two SCAs)

Width of the field = (4 x 6) + (3 x 12) = 60 m

Total area required =

Length of the field x Width of the field

Total area required = 230 x 60
= 13800 m² = 3.41 Acre

6. SOLAR PARABOLIC TROUGH PLANT DESIGN FOR YEAR 2019 AND 2024

In this section solar parabolic trough power plant is designed for village Mansarkheri with the considerations of 2019 and 2024 year energy requirements. All the design parameters are calculated and has been tabulated in table-11.

Table-11: Design parameters of SPV plants for year 2019 and 2024

Design parameters	SPT 2019	SPT 2024
Rating of SPT plant (kW)	451.24	641.88
Solar collector area (m²)	3460	4920
Number of loops	2	2
Number of solar collector assemblies	16	16
Number of solar collector elements	128	128
Number of receiver tubes	384	384
Land required (Acre)	3.41	3.41

7. PROJECT COST

Project cost of SPT power plants have been calculated according to the capital cost of the SPT plant in respective year. Capital cost from 2012 to 2015 are taken from order of central electricity regulatory commission and tabulated in Table-12. [10], [11], [12], [13], [14], [15], [16], [17], [18]. Capital cost pf SPT plant for year 2019 and 2024 has been obtained by forecasting which are 1101.50 Rs.lakh/MW and 1012.03 Rs.lakh/MW for year 2019 and 2024 respectively. According to these capital costs, project cost of spv plant for year 2015,2019 and 2024 have been calculated and tabulated in table-13.

Table-12: Capital Cost for SPT Power plant in Rs. Lakh/MW for years 2012-2015

S.No.	Particulars/Years	2012	2013	2014	2015
1	Collector	572.00	528.00	528.00	528.00
2	Storage	234.00	216.00	216.00	216.00
3	Contingencies	156.00	144.00	144.00	144.00
4	Electricity generation	130.00	120.00	120.00	120.00
5	Consultancy	78.00	72.00	72.00	72.00
6	Balance of plant	52.00	48.00	48.00	48.00
7	Heat exchangers	39.00	36.00	36.00	36.00
8	Structures	20.06	20.50	20.88	21.25
9	Land	10.03	10.25	10.44	10.63
10	Total capital cost	1291.09	1194.75	1195.31	1195.88

Table-13: Project cost of SPT plants in Rs. Lakh/MW

S.No.	Particulars/Years	SPT2015	SPT 2019	SPT 2024
1	Collector cost	165.06	218.40	283.31
2	Storage cost	67.52	89.35	115.90
3	Contingencies cost	45.02	59.56	77.27
4	Electricity generation cost	37.51	49.64	64.39
5	Consultancy cost	22.51	29.78	38.63
6	Balance of plant cost	15.01	19.85	25.76
7	Heat exchangers cost	11.25	14.89	19.32
8	Structures cost	6.64	10.38	16.69
9	Land cost	3.32	5.19	8.34
10	Capital cost	373.84	497.04	649.60
11	Capital cost with 30% capital subsidy	261.69	347.93	454.72

8. CONCLUSION

In this study Electrical energy required by the village Mansarkheri is estimated for year 2015, 2019 and 2024 and solar parabolic trough power plant is proposed and design parameters are calculated accordingly. Following conclusions can be drawn from the study.

(i).Total electrical energy demand of village Mansarkheri is found to be 638.25 MWh/annum, 821.27 MWh/annum and 1072.01 MWh/annum for year 2015, 2019 and 2024 respectively.

(ii).According to this electrical energy demand solar parabolic trough power plant of capacity 312.61 kW 451.24 kW 641.88 kW are proposed and designed for year 2015, 2019 and 2024 respectively.

(iii).For Solar parabolic trough plant 2015, 3000 m^2 of solar collector area, 2 loops, 16 solar collector assemblies,128 solar collector elements, 384 receiver tubes and 3.41 acre area required.

(iv).For Solar parabolic trough plant 2019, 3460 m^2 of solar collector area, 2 loops, 16 solar collector assemblies,128 solar collector elements, 384 receiver tubes and 3.41 acre area required.

(v).For Solar parabolic trough plant 2024, 4920 m^2 of solar collector area, 2 loops, 16 solar collector assemblies,128 solar collector elements, 384 receiver tubes and 3.41 acre area required.

(vi).Capital cost solar parabolic trough power plants are found to be 1195.88 Rs.lakh/MW, 1101.50 Rs.lakh/MW and 1012.03 Rs.lakh/MW for year 2015, 2019 and 2024 respectively.

(vii).According to these capital costs, the project cost of the solar parabolic trough plants are calculated which are 373.84 Rs.lakh, 497.04 Rs.lakh and 649.60 Rs.lakh for year 2015, 2019 and 2024 respectively.

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