International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 11 | Nov -2017 www.irjet.net p-ISSN: 2395-0072

Design of solar photovoltaic plant for a village in Rajasthan

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Abstract - *In this paper a solar photovoltaic plant has been proposed and designed for a village Mansarkheri located in Jaipur district in order to supply the electrical energy demand of the village by renewable energy oriented technology. A quessionaire based survey is conducted in village Mansarkheri during year 2014 in order to collect energy consumption data. Also the electrical energy demand of the village has been estimated as 584.60 MWh/annum for the year 2014 as per the survey data. The electricity consumption data of the village is also collected from distribution company and the electrical energy demand has been estimated as 557.12 MWh/annum as per bill data for year 2014. In this study solar photovoltaic plant has been designed for the electrical energy requirements of the village Mansarkheri in 2015, 2019 and 2024.The electrical energy consumption data from year 2010 to 2014 has been collected from electricity Distribution Company and forecasted by using linear regression method in order to find energy consumption data of year 2015, 2019 and 2024. Capital costs of solar photovoltaic plant from year 2010 to 2015 have also been forecasted in order to find capital cost for year 2019 and 2024. The annual energy required by the village Mansarkheri is 638.25 MWh/annum, 821.27 MWh/annum and 1072.01 MWh/annum in year 2015, 2019 and 2024 respectively. To supply this energy demand solar photovoltaic power plant of capacity 395.34 kW, 508.71 kW, 664.02 kW respectively are proposed and designed for year 2015, 2019 and 2024.*

Key words: Solar photovoltaic plant, Survey, Electrical energy demand

1. INTRODUCTION

Mansarkheri village is located in Bassi sub division of Jaipur district in Rajasthan (latitude **26˚83'N**, longitude **76˚05'E,** altitude **351 m**). This village is a small village with population of 3662 people and 513 households. The villagers in this village use electricity for household purpose and also for agricultural purpose, and for this they rely on JVVNL (Jaipur vidhyut vitaran nigan limited) which is a local electricity distribution company of Rajasthan state government. These days continuous and un-interrupted power supply is the biggest problem in rural India. Therefore there is a need for sustainable as well as eco friendly technology based power generation sources in order to supply the electrical energy requirement of the villages.

Jose and Miller [1] analyzed the available decentralized generation potential in Liberia in order to provide the electrical energy to the rural population of the Liberia. They calculated the suppressed demand of electricity required by the rural population of the Liberia which is 235 GWh/yr. **Sapkota et al. [2]** analyzed the role of different renewable energy technologies for the rural population of Nepal in order to adapt the climate change. **Ghafoor and Munir [3]** showed a study in which they analyzed a standalone type photo-voltaic system not connected to grid (off grid) for the purpose of electrification of a single residential house located in Faisalabad Pakistan.They also concluded that the off grid photovoltaic system is technically as well as economically feasible for electricity generation purpose for residential demand. **Blenkinsopp et al. [4]** presented the results of energy survey which is conducted in rural areas of Maharashtra. The result of the study showed that there is a great interest regarding the use of these sustainable renewable energy technologies but instead of environment issues they prefer the cost, maintenance, reliability and ease of use of these technologies. **Pandey and Chaubal [5]** used the household information data from 61st round of NSSSO survey and explained the determinants for tendency of use of clean fuel for cooking purpose by using logistic regression model. **Millinger et al. [6]** carried out a case study in Chattisgarh state of India in order to find the impact of solar power electrification on beneficiaries. In those villages where the systems for purpose of electrification are installed, the children found to be studied 41 minutes more as compared to before electrification in evening time. **Borah et al. [7]** presented the comparative analysis among four solar energy based technologies i.e. Solar Home System, Solar AC Mini Grid, Solar Charging Station and Solar DC Micro Grid which are used for purpose of electrification and also surveyed the selected photovoltaic programs in India.

2. ENERGY DEMAND ESTIMATION

Energy consumption data of the village Mansarkheri is collected by questionnaire based survey. The sample survey is first done in order to find out shortcomings in survey template and after this actual survey template is made by doing some modification in sample survey template. In Mansarkheri village 50 households are selected in equal and These 50 households are surveyed and data is collected. By using these data per capita electricity consumption is calculated and by multiplying

this per capita consumption with the total population of the village, total consumption of the village is calculated. The population related data of village is also collected from Census Authority of the Rajasthan in which the population of the village from 1951 census to 2011 census is mentioned. Energy consumption data is also collected from electricity bills provided by the local electricity distribution company which is tabulated in Table-1.

Table-1: Consolidated electricity consumption data of Mansarkheri village

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

Energy and power requirements of village Mansarkheri for year 2014 are tabulated in table-2. 7 hours are taken as operating hours per day.

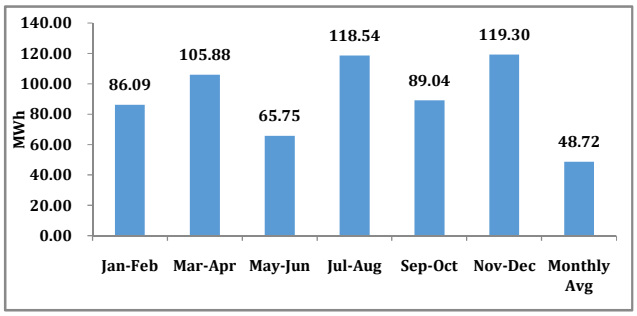

Figure-1: Bi-monthly energy consumption of village Mansarkheri in MWh for 2014

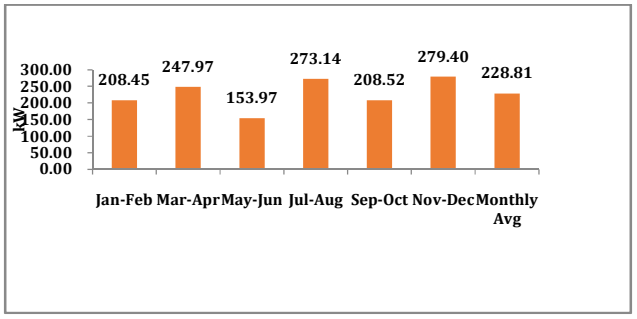

Figure-2: Bi-monthly power requirement of village Mansarkheri in kW for 2014

Figure-1 is showing the variations of energy consumption with each bi-month and also for monthly average case in year 2014 for village Mansarkheri. This plot is showing that maximum demand is occurring in Nov-Dec bi-month in year 2014 for village Mansarkheri.

Figure-2 is showing the variations of power consumption with each bi-month and also for monthly average case in year 2014 for village Mansarkheri. This plot is showing that maximum power is required in Nov-Dec bi-month in year 2014 for village Mansarkheri.

3. POPULATION AND ENERGY CONSUMPTION FORECASTING

In this section population and per capita energy consumption of village Mansarkheri is forecasted by using linear regression method in order to find energy consumption for year 2015, 2019 and 2024.

Population data from year 1951 to 2011 has been forecasted in order to obtain population for 2015, 2019 and 2024 year and tabulated in table-3. The population data of year 1951, 1961, 1971, 1981, 1991, 2001 and 2011 is known which is collected from the directorate of census office Jaipur and the population data of year 2012 to 2024 is obtained by using forecasting.

Annual electricity consumption is calculated by multiplying the annual per capita consumption with the population of the village in that year. Table-4 is showing the per capita electricity consumption data of village Mansarkheri from year 2010 to 2024. Table-5 and Table-6 are showing the bi-monthly electricity consumption data and power requirement of village Mansarkheri from year 2010 to 2024 respectively.

Table-5: Bi-monthly energy consumption in MWh of Mansarkheri for 2010-2024

Year	Feb	Apr	Jun	Aug	Oct	Dec
2010	57.45	67.65	77.56	95.29	55.08	79.46
2011	74.91	75.57	62.45	78.43	78.73	65.00
2012	62.68	57.36	92.57	96.54	123.08	110.21
2013	87.80	104.36	110.33	98.21	95.81	79.50
2014	99.11	61.54	110.96	83.34	111.67	101.50
2015	105.99	78.48	126.09	89.02	133.49	105.18
2019	149.09	85.69	176.07	86.52	192.68	131.22
2024	208.29	95.13	245.47	82.37	274.08	166.67

Table-6: 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 PHOTOVOLTAIC 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.

4.2. Electrical Energy requirement from PV modules

For solar photovoltaic power plant losses are considered as 30 % therefore 30 % additional of the total requirements has to be designed. [9]

Total electrical energy required by the village in 2015 year = 638.25 MWh

Total electrical energy required from PV modules =1.3 × 638.25=829.73MWh/Year (2.27MWh/day)

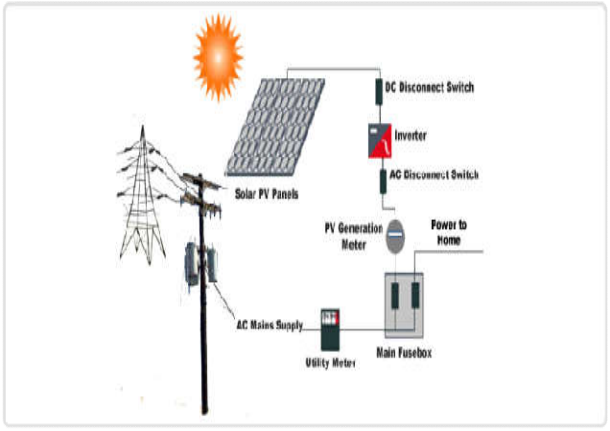

Figure-3: General diagram of a solar photovoltaic power plant [10]

4.3. PV modules

Renesola 156 series solar module JC250S-24/B_b is selected to develop the solar field of the solar photovoltaic plant. Renesola 156 series solar module JC250S-24/Bb is a mono-crystalline solar module inbuilt with ingot growth technology which improves the uniformity of the grains and preferred orientation resulting in higher minor-carrier lifetime and lower dislocation density. This phenomenon increases the module efficiency. Technical specifications of the PV module are tabulated in Table-7.

4.4. PV modules Total watt peak rating

Total electrical PV modules total watt peak rating is the ratio of electrical energy required from PV modules and panel generation factor of the location selected.

$$\text{PV modules total watt peak rating} = \frac{\text{Energy required from PV modules}}{\text{Panel generation factor}}$$

$$\text{PV modules total watt peak rating} = \frac{2.27\ \text{MWh/day}}{5.75\ \text{hours/day}} = 395.34\ \text{kW}$$

4.5. PV modules requirement

PV modules requirement is the total number of the PV panel which are required to generate the desired power and can be calculated by given formula

$$\text{Total number of PV modules required} = \frac{\text{PV modules total watt peak rating}}{\text{PV module peak rated output}}$$

$$\text{Total number of PV modules required} = \frac{395.34 \times 10^3}{250} = 1577.36 \sim 1596\ \text{modules}$$

Maximum open circuit dc voltage of string = 780 V

Open circuit voltage of PV module = 37.5 V

$$\text{Number of PV modules connected in series} = \frac{\text{Maximum open circuit dc voltage of string}}{\text{Open circuit voltage of PV module}}$$

$$\text{Number of PV modules connected in series} = \frac{780}{37.5} = 20.8 \sim 21 \text{ Pannels}$$

Maximum power dc voltage of PV module = 30.1 V

Maximum power dc voltage at the input terminals of inverter

=Number of PV modules connected in series ×Maximum power dc voltage of PV module

$$= 21 \times 30.1 = 632.1 \text{ V}$$

$$\text{Number of PV arrays required} = \frac{\text{Total number of PV modules required}}{\text{Number of PV modules connected in series}}$$

$$\text{Number of PV arrays required} = \frac{1596}{21} = 76 \text{ arrays}$$

4.6. Inverter

Leonics Apollo GTP series inverters are selected to convert the dc output of solar PV modules in to AC power output. As the inverter sizing is dependent on maximum demand therefore based upon the maximum demand of the village Leonics Apollo GTP series inverter 509 is selected. The technical specifications of the inverter are tabulated in Table-8.

Table-7: Technical specifications of Renesola 156 series solar module JC250S-24/B_b [11]

S. No.	Parameter	Units	Values
1	Maximum power (P_{max})	W	250
2	Max. power voltage (V_{pm})	V	30.1
3	Max. power current (I_{pm})	A	8.32
4	Open circuit voltage (V_{OC})	V	37.5
5	Short circuit current (I_{SC})	A	8.87
6	Power tolerance	W	(0) to (+5)
7	Module efficiency	%	15.4
8	Maximum system voltage	V_{dc}	1000
9	Temperature coefficient of Pmax	%/ ˚C	-0.43
10	Temperature coefficient of V_{OC}	%/ ˚C	-0.31
11	Temperature coefficient of I_{SC}	%/ ˚C	0.03
12	Maximum series fuse rating	A	20
13	Operating temperature	°C	(-40) to (+85)

Table-8: Technical specifications of Leonics Apollo GTP series inverters [12]

S. No.	Parameters/Model	GTP-509
1	Rated power at PV input (kW)	198
2	Rated power at AC output (kW)	180
3	MPPT voltage range (V_{mp} of PV string) V_{dc}	400-700
4	Max open circuit voltage(V_{oc} of PV string)	780
5	Max PV current (A)	450
6	Power factor	> 0.98
7	Total harmonic distortion	< 3 %
8	Max AC current (A)	272.2
9	Inverter peak efficiency	> 96 %
10	Power consumption (W)	< 40
11	Temperature (°C)	0-45
12	Relative humidity	0-95 %
13	Enclosure	IP 20

4.7. Inverter requirement

The size of inverter is the function of the maximum demand occurring at the load side therefore inverter size must be selected in accordance with the peak power requirement of the load. The maximum demand of the village is 312.61 kW. Therefore inverter size = 312.61 kW.
Number of APOLLO GTP-509 inverters required =2

Total wattage supported by the inverter =Number of inverters × wattage of inverter

$$= 2 \times 180 \text{ kW} = 360 \text{ kW}$$

Table-2: Energy and power requirements of village Mansarkheri in 2014

Bill Data								Survey Data
Month	**Jan-Feb**	**Mar-Apr**	**May-Jun**	**Jul-Aug**	**Sep-Oct**	**Nov-Dec**	**Monthly Average**	**Monthly Average**
Total consumption of village in MWh	86.09	105.88	65.75	118.54	89.04	119.30	48.72	46.43
Days in each Bi-monthly period	59	61	61	62	61	61	30.42	30.42
Total operating hours in each Bi-month	413	427	427	434	427	427	212.92	212.92
POWER(kW)	208.45	247.97	153.97	273.14	208.52	279.40	228.81	218.06

Table-3: Population forecasting [8]

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

Table-4: 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

Table-10: Capital Cost for Solar PV Power plant in Rs. Lakh/MW for years 2010-2015

S.No.	**Particulars/Years**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	PV Modules Cost	915	833	494	344.50	334.00	332.35
2	Land Cost	5	15	16	16.80	18.00	25.00
3	Civil and General Works Cost	90	95	90	94.50	50.00	50.00
4	Mounting Structures Cost	80	105	100	105.00	40.00	50.00
5	Power Conditioning Unit Cost	180	160	98	60.00	50.00	45.00
6	Evacuation Cost up to Inter-connection Point (Cables and Transformers) Cost	85	90	100	105.00	60.00	55.00
7	Preliminary and Pre-Operative Expenses including IDC and contingency Cost	165	144	80	80.00	60.00	48.50
8	Capital Cost	1520	1442	978	805.8	612	605.85

Table-11: Project cost of SPV plants

S.No.	**Particulars/Years**	**SPV 2015**	**SPV 2019**	**SPV 2024**
1	PV Modules Cost	131.39	155.96	183.40
2	Land Cost	9.88	17.97	33.07
3	Civil and General Works Cost	37.26	50.08	67.92
4	Mounting Structures Cost	45.46	69.95	107.59
5	Power Conditioning Unit Cost	17.79	22.89	29.88
6	Evacuation Cost up to Inter-connection Point (Cables and Transformers) Cost	47.44	75.03	121.24
7	Preliminary and Pre-Operative Expenses including IDC and contingency Cost	19.17	24.67	32.20
8	Capital Cost	**308.40**	**416.55**	**575.30**
9	Capital cost with 30% capital subsidy	**215.88**	**291.58**	**402.71**

4.8. Land requirement

Width of PV panel = 992 mm = 0.992 m

Number of PV modules connected in series = 21panels

Width of PV array

=Width of PV panel ×
Number of PV modules connected in series

Width of PV array =0.992 × 21 = 20.83 m

Length of PV panel = 1640 mm = 1.64 m

Number of PV arrays = 76

Number of PV arrays in a row =4

Width of solar PV field

= Width of PV array × Number of PV arrays in a row

Width of solar PV field = 20.83 × 4 = 83.32 m

Number of PV arrays rows in solar field = 19

Separation between two PV arrays = 3 m

Length of solar PV field =

(Number of PV arrays rows in solar field − 1) ×
Separation between two PV arrays

Length of solar PV field = (19 − 1) × 3 = 54 m

Total land required

=Length of solar PV field × Width of solar PV field

Total land required = 54 × 83.32 = 4499.28 m^2 = 1.11 Acres

Table-9: Design parameters of SPV plants for year 2019 and 2024

Design parameters	SPV 2019	SPV 2024
Energy required from pv modules(MWh/year)	1067.65	1393.61
Total watt peak rating(kW)	508.71	664.02
Number of modules required	2037	2667
Inverter size (kW)	451.24	641.88
Number of series connected modules	21	21
Number of pv arrays	97	127
Land required(acres)	1.48	1.91

5. SOLAR PHOTOVOLTAIC PLANT DESIGN FOR YEAR 2019 AND 2024

In this section solar photovoltaic power plant is designed for village Mansarkheri with the considerations of 2019 and 2024 year energy requirements. All the design parameters are calculated and have been tabulated in table-9.

6. PROJECT COST

In the designing of solar photovoltaic plants in year 2015, 2019 and 2024 the capital costs are required according to those year considerations. The capital cost of SPV plant of year 2010 to 2015 is available which are tabulated in Table-10. [13], [14], [15], [16], [17], [18], [19], [20]

The capital cost of the solar photovoltaic power plant in year 2019 and 2024 is required therefore based upon the available capital costs from year 2010 to 2015 tabulated in Table-10, the capital costs in year 2019 and 2024 are obtained by using linear regression based forecasting. Capital cost of spv plant is estimated as 818.84 Rs.lakh/MW and 866.39 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-11.

7. CONCLUSION

In this study a village Mansarkheri is selected and the electricity demand of the village is estimated for years 2015, 2019 and 2024. Now to supply the electricity, demands of year 2015, 2019 and 2024 renewable energy technology based energy generation systems i.e. solar photovoltaic power (SPV) plants are proposed. These renewable energy based energy generation systems i.e. solar photovoltaic power (SPV) plants are found to be technologically feasible, economically viable options of energy generation and also environmentally acceptable as the solar energy is the clean source of energy. Following are the conclusions-

(i).The annual energy required by the village Mansarkheri is 638.25 MWh/year, 821.27 MWh/year and 1072.01 MWh/year in year 2015, 2019 and 2024 respectively. To supply this energy demand solar photovoltaic power plant of capacity 395.34 kW, 508.71 kW, 664.02 kW are proposed and designed in year 2015, 2019 and 2024 respectively.

(ii).To design the solar photovoltaic plant for year 2015,1596 solar modules are required in which 76 arrays of PV modules are designed having 21 PV modules connected in series in each array.

(iii).Also in the design of solar photovoltaic plant for 2019 and 2024 year, 2037 and 2667 PV modules are required respectively.

(iv).The capital cost of the solar photovoltaic (SPV) power plant is 780.10 RS.Lakh/MW,818.83 RS.Lakh/MW and 866.39 RS.Lakh/MW in year 2015, 2019 and 2024 respectively.

(v).According to these capital cost rates the solar photovoltaic power plant project cost for village Mansarkheri are calculated as 308.40 RS.Lakh, 416.55 RS.Lakh, 575.30 RS.Lakh for without subsidy and 215.88 RS.Lakh, 291.58 RS.Lakh, 402.71 RS.Lakh when 30% capital subsidy is given by government in year 2015, 2019 and 2024 respectively.

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