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Grid-Connected Distributed Captive PV Power Plants For Ludhiana District - A Case Study

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Abstract- *Solar energy is most promising clean renewable energy source with large potential. Solar PV power plants can be installed as large utility-scale power plants as well as smaller distributed captive power plants. This is so because solar energy is distributed energy source and PV power plants do not enjoy significant economy of scale. In this paper, an investigation regarding installation of distributed captive solar PV power plants connected to feeders at different points to replace 100% of the grid electricity supplied in Ludhiana district of state of Punjab (India) has been reported. It was found that most of the electricity (83%) is supplied to urban areas while only 17% is supplied to rural areas. In rural areas, large number of smaller distributed captive PV power plants can be installed to meet the distributed electric load as plenty of land is available. For urban areas, it is essential to install large utility-scale PV power plants far away from cities where cheaper land may be available as land on the periphery of cities is very expensive. However rooftop PV systems can be installed to partially meet the electric load in urban areas. First preference should be given to installation of distributed PV power plants in villages.*

Keywords: *Distributed captive PV plants, Economy of scale, PV plants near villages, PV power plants for Ludhiana.*

I. INTRODUCTION

Thermal and hydro power plants are always installed as large utility-scale power plants with capacities in the range of few hundred to few thousand megawatts due to economics of scale. The large amount of electricity generated in such power plants is transmitted over long distance to various substations and then distributed to consumers in nearby villages, towns and cities. Utility-scale power plants with large amount of electricity generation tend to be more suitable for concentrated consumers in cities and towns with large concentrated load. Solar energy is distributed energy source and solar PV power plants do not enjoy significant economy of scale. Therefore it is possible to install distributed captive PV power plants in rural areas to meet the distributed electric load of distributed villages. Such distributed captive PV power plants tend to be more suitable for rural areas because of small distributed electric load in villages and availability of cheaper land. Further by generating solar electricity close to the consumers, transmission cost is eliminated and distribution losses are reduced. Obviously, the best option is to install small captive PV systems on the premises of users with zero transmission and distribution costs e.g. rooftop PV systems. The next best option is to install distributed captive PV power plants near the group of captive users e.g. captive PV power plant near a big village or cluster of smaller villages.

In this paper installation of distributed PV power plants on feeders distributing electricity to consumers from various substations in Ludhiana district of Punjab state (India) have been explored.

II. LITERATURE REVIEW

The concept of distributed captive power plants near villages is new. There fore, no literature exists for such PV power plants. However, distributed captive rooftop PV systems on the roofs of residential, commercial and industrial buildings are being installed in large numbers throughout the world. Therefore, few papers on distributed captive rooftop PV systems have been discussed.

The paper analyses the growth and development of solar energy globally as well as policies of various countries regarding rooftop PV systems [1]. The present and future scenario of solar energy development in India has also been discussed. India has made a commitment to increase its renewable source based energy capacity to 175 GW by 2022 with a share of 100 GW of solar energy exclusively. The solar rooftop systems are the potential solar power generation options. The paper reviews the issues and challenges and latest trends in the development of solar energy. The study recommends linking of solar energy with current missions on 'Make in India', 'Smart city mission' and 'Digital India'. Indian government has already launched a prestigious project under the name 'Jawaharlal Nehru National Solar Mission' (JNNSM) to be completed in three phases by 2022 to encourage the generation of solar power and to take care of climate. Laws are also needed to be made for new buildings to be rooftop ready.

Importance of fast growth of solar power and of solar photovoltaic power in particular all over the world has been emphasized [2]. Drastic cut in the cost of solar PV panels has made solar power an attractive option and alternative to the hydrocarbon fuels in Middle East and North African (MENA) countries. Presently rooftop solar PV systems are becoming popular in United Arab Emirates' (UAE) future energy mix. The paper discusses the case study of rooftop solar power in UAE to make it a sustainable power generation mix. The study proves that rooftop solar PV technology can be economically viable option for power generation. The use of rooftop solar PV systems helps in reducing the peak demand and the requirement of transmission and distribution system addition.

A study of performance of a 20 kW_p grid connected PV system installed at the rooftop of the library of IISc, Bangalore, India, under different weather conditions has been carried out [3]. The objective of the paper was to study the effect of climate conditions on the performance of PV system. It is concluded that the major factor influencing the output of any PV system is the module temperature. The lower the temperature, the higher will be the output. The study reveals that the average performance ratio is inversely proportional to the module or cell temperature. Therefore to obtain maximum output from rooftop systems the module surface temperature should be kept low.

The performance of a 110 kW_p PV rooftop grid connected system installed at a residential hostel building at Bhopal, India has been evaluated through Solargis PV Planner software [4]. The output of four different PV technologies has been studied and found that Solargis is fast, accurate and reliable software for simulation of solar PV system. The performance ratio of PV systems has been found to vary from 70% to 88% and the energy output was found between 2.67 kWh/kW_p to 3.36 kWh/kW_p.

The paper has estimated the rooftop PV potential in commercial and residential areas of three leading states of USA: California, Arizona & New Jersey [5]. It has been found that rooftop PV system can provide 35%, 43% and 61% of electricity requirement in the states of New Jersey, Arizona and California respectively. The analysis reveals that the installed capacity of solar PV systems in these states can increase by 20 times, 30 times and 40 times respectively.

Informational barriers in the growth of solar PV systems have been investigated [6]. The survey was conducted on PV system in Northern California. During the analysis of various informational barriers i.e. motivating factors, information gathering, peer effects, role of installers etc., it has been found that installers and neighbors play a vital role for decision making. Also the fiscal returns and operation and maintenance are the main decision determining factors to adopt the solar PV system.

Performance of grid-connected rooftop PV system of 2 kW_p was experimentally evaluated in Serbia. The annual specific yield factor was found to be 1161.70 kWh/kW_p while performance ratio was 93.6% [7]. The electricity generation of 3 kW_p Si based PV roof top systems in Korea has been studied under four distinct seasons [8]. The effect of type of module and tilt angle on the energy output was compared with data obtained from computer simulation. The measured electrical energy yield was found comparable with the simulated data. It was found that the performance of Si based PV systems operated under different seasons could be improved by changing the tilt angle between 10° and 35°.

Two rooftop PV systems consisting of amorphous silicon and mono-crystalline silicon wafer panels were investigated in Italy [9]. Performance ratio was found to be 89.1% and 82.7% respectively.

Performance evaluation of seven roof supported PV systems in Abu Dhabi, UAE was evaluated [10]. The evaluation has been carried out using 'PVsysts Project Design' software on monthly and daily basis. The PV systems consisted of amorphous silicon (a-Si) and poly crystalline silicon (p-Si) PV technologies. The study showed that the seven simulated PV systems with a total installed capacity of 1023.08 kW_p can save up to 1500 tons of CO_2 emissions annually. The performance of PV (a-Si) system were found to be higher than p-Si PV system

Analysis of factors influencing the performance of PV system installations in Singapore is presented [11]. The effect of rooftop material and other environmental conditions on the module temperature has been studied. Variance in module temperature was higher than changes in ambient temperatures. The study suggests guidelines for optimized performance of PV systems in tropical regions.

The performance evaluation of a 1.72 KW_p rooftop grid connected PV system installed on the roof of a flat in Dublin, Ireland has been studied [12]. The electricity generated was fed into the low voltage supply to the flat. Almost all the parameters like annual energy output, annual average daily final yield, reference yield and array yield were monitored during study. The total energy generated annually was found to be 885.1 kWh/kW_p.The performance comparison of this system with other systems in different locations showed that the system had the highest system efficiency and performance ratio of 12.6% and 81.5% respectively. The results were found comparable to the results from some parts of Spain but lower than that of Italy. Ireland's suitability due to high average wind speed and low ambient temperature has been found better. Also it was found that daily average yield of 2.4 kWh/kW_p was higher than that found in Germany, Poland and Northern Ireland.

Rooftop solar PV system was investigated in Italy. Solar PV systems installed on the roofs and facades of buildings in a university in Italy provided more than 80% of its electricity needs [13].

III. METHODOLOGY

Power generated at the hydro and thermal power plants is transmitted to large number of distributed substations at high voltage of 132 kV, 220 kV or higher. At substations, voltage is stepped down to 11 kV and distributed to various villages, towns and cities through 11 kV feeders. The 11 kV supply is further stepped down to 440 volts through distribution transformers installed near the consumers. Feeders are of different categories because the timings and hours of electricity supply are different for different categories of consumers. The 11 kV feeders are of six categories:

a) AP feeders- Feeders for rural areas to supply electricity exclusively to tubewells for agricultural purposes.
b) UPS feeders- Feeders for rural areas to supply electricity to meet the residential and commercial load of villages.
c) Category-1 feeders- Feeders for urban areas to meet the residential and commercial load and small amount of industrial load (less than 80 % of the total load on the feeder).
d) Category-2 feeders- Feeders for urban areas to meet the industrial load (more than 80% of total load on the feeder) and small amount of residential and commercial loads.
e) Category-3 feeders- Independent feeders for urban areas to meet the demand of electricity of large industrial and commercial consumers having connected load of 2500 KVA and above.
f) Category-4 feeders- Independent feeders for urban areas to meet the demand of electricity of continuous process industries e.g. plastic industry, spinning industry and essential services etc.

The electricity supplied through each feeder at each substation is metered. This metered data for all the substations of Ludhiana district of Punjab (India) is available with Punjab State Power Corporation Limited (PSPCL). So the data used in this paper has been obtained from PSPCL. The initial investment required per MW_p capacity of solar PV power plant has been taken as 5.05 crore rupees and land requirement has been taken as 5 acre/MWp [14]. It has been assumed that land for PV power plants will be taken on rent with long term agreement.

IV. RESULTS AND DISCUSSION

The first step was to determine average capacity utilization factor for PV power plants in Punjab. This value of average capacity utilization factor was coupled with data of electricity supplied through each feeder during 2014-15 at different substations in Ludhiana district to determine the capacity of PV power plants required to be installed on each feeder to replace 100% of electricity supplied. Then the requirements of land and initial investment of PV power plants on each feeder were determined.

4.1 Capacity utilization factor for Punjab

To determine the capacity utilization factor for solar PV plants in Punjab, the data was collected regarding capacity and the annual solar electricity generated for eleven existing PV power plants (Table1). The calculated values of specific output and capacity utilization factor of each PV power plant are also shown in Table 1. The specific output varies from 873.49 to 1670.88 MWh/MW_p-year. The corresponding variation in capacity utilization factor is from 9.97 to 19.07 %. This variation in specific output may be due to the fact that PV panels used in these PV power plants are of different makes. The total capacity of the eleven existing solar PV plants is 55.02 MW_p and total annual electricity generated is 81796.88 MWh. Therefore, the average specific output turns out to be 1486.67 MWh/MW_p-year. It has been approximated as 1500 MWh/MW_p-year. The corresponding average capacity utilization factor turns out to be 17.12%. This average value of capacity utilization factor has been used for calculations in this paper.

4.2 Typical substations located in rural and urban areas

There are 78 substations in Ludhiana district of state of Punjab (India). Each substation supplies electricity to consumers in specified area through different categories of 11 KV feeders. Few substations are located completely in rural area to supply electricity to tubewells for agricultural purposes through AP feeders and to villages for residential and commercial purposes through UPS feeders. Electricity supply to AP feeders is given for limited hours depending upon the irrigation requirements of crops in the area covered. Electricity supply to villages through UPS (Urban Pattern Supply) feeders for residential and commercial purposes is for 24 hours per day just like urban areas.

Table 1. Power generation data of few solar PV power plants installed in Punjab state

Sr.No	Name of project	Capacity (MW_p)	Total power generation during 2014-15 (MWh)	Specific output (MWh/MW_p-year)	Capacity utilization Factor (%)
1	Phulokheri SPV	1	1408.48	1408.48	16.08
2	NVVN Bundled	35	58480.97	1670.88	19.07
3	Soma Plant	1	1269.35	1269.35	14.49
4	Carlill Energy Bhagsar	1.5	2188.24	1458.83	16.65
5	Econenergy Boparai	1	1224.52	1224.52	13.98
6	G.S.Atwal Bhuttiwal	1.5	2204.33	1469.55	16.78
7	Sovax Renewables Solar	1	964.14	964.14	11.01
8	EBS	1.5	1377.62	918.41	10.48
9	RSSB (Roof top)	7.52	9058.57	1204.6	13.75
10	Madhav-I	2	1873.67	936.84	10.69
11	Madhav-II	2	1746.98	873.49	9.97
		55.02	81796.88		

Few substations are located on the periphery of cities and towns. Such substations supply electricity to both rural and urban areas. Other substations supply electricity to urban areas for residential, commercial and industrial purposes. One typical substation each located in rural area, on periphery of town/city and urban area has been discussed below to give some idea about electricity consumed through different categories of feeders for different purposes.

(i) Typical substation located in rural area

Rural substations supply electricity to tubewells in the fields for agricultural purposes through AP feeders. Each AP feeder caters to large number of tubewells distributed in number of villages. A typical tubewell has 10-15 kW capacity and irrigates few acres of land. In this way load of tubewells on AP feeder is small and widely distributed load. Similarly each UPS feeder supplies electricity to 30-50 villages for residential and commercial purposes. Most of this electricity is used for residential purposes because there are few commercial activities in the villages. Again, it is small distributed load of large number of households.

The results for a typical substation named 'Heddon Bet' located in rural area have been discussed here. The Heddon Bet substation has four AP feeders and one UPS feeder. Electricity supplied and capacity of PV power plants as well as required land and initial investments are given in the Table 2.

The capacity of PV power plants for AP feeders which supplies electricity for tubewells varies from 0.60 MW_p to 1.40 MW_p. Corresponding land requirement varies from 3.00 acres to 7.00 acres. One possibility is to install one PV power plant on each AP feeder near the substation but it will be better to install number of smaller PV power plants along the feeder as such plants get closer to the consumer. If load is not too small then it possible to install one captive PV power plant for each village to feed electricity to captive consumers of that village.

The Heddon Bet substation has one UPS feeder which supplies electricity to 61 villages for residential and commercial purposes. This feeder requires solar PV power plant of 5.73 MW_p with corresponding land requirement of 28.65 acres. It is possible to install one PV power plant near the substation but it will be better to install number of smaller PV power plants along the feeder as such plants get closer to the consumer and smaller pieces of land at different places is required.

Total electricity supplied during the year 2014-15 through five feeders was 14161 MWh. Out of this 5560 MWh of electricity (39.26 %) was supplied through four AP feeders and 8601 MWh (60.74 %) through one UPS feeder. It may be noted that electricity used for running tubewells is much smaller than the electricity used for residential and commercial purposes in villages.

Table 2. Proposed distributed captive solar PV power plants connected to grid on 11 KV distribution side for Heddon Bet electric grid substation.

Sr.No	Name of project	Capacity (MW_p)	Total power generation during 2014-15 (MWh)	Specific output (MWh/MW_p-year)	Capacity utilization Factor (%)
1	Phulokheri SPV	1	1408.48	1408.48	16.08
2	NVVN Bundled	35	58480.97	1670.88	19.07
3	Soma Plant	1	1269.35	1269.35	14.49
4	Carlill Energy Bhagsar	1.5	2188.24	1458.83	16.65
5	Econenergy Boparai	1	1224.52	1224.52	13.98
6	G.S.Atwal Bhuttiwal	1.5	2204.33	1469.55	16.78
7	Sovax Renewables Solar	1	964.14	964.14	11.01
8	EBS	1.5	1377.62	918.41	10.48
9	RSSB (Roof top)	7.52	9058.57	1204.6	13.75
10	Madhav-I	2	1873.67	936.84	10.69
11	Madhav-II	2	1746.98	873.49	9.97
		55.02	81796.88		

(ii) Typical substations located near the cities/towns

Substations located near city meet load of both rural and urban areas. Therefore such substations have feeders of category 1-4 in addition to AP and UPS feeders. Category 1-4 feeders supply electricity to meet residential, commercial and industrial load of urban areas. The AP and UPS feeders supply electricity to tubewells and residential and commercial load of villages respectively. Results for one such substation named ‘Adda Dakha’ which is located on the periphery of town ‘Adda Dakha’ have been discussed. The results are given in Table 3. The substation Adda Dakha has 15 feeders. There are 8 AP feeders supplying electricity to tubewells for growing various crops. These feeders require solar PV power plants of capacity in the range 1.53 MW_p to 3.74 MWp. The land requirement varies from 7.65 acres to18.72 acres. Again it is possible to install one PV power plant on each AP feeder near the substation but it is better to install number of smaller PV plants along the feeders. There are 4 UPS feeders supplying electricity for residential and commercial purposes in villages. These feeders require solar PV power plants of capacity in the range 3.53 MW_p to 9.67 MW_p. The land requirement varies from 17.67 acres to 48.35 acres.

There are two category–1 feeders which supply electricity to urban area (town) for residential and commercial purposes. These feeders require solar PV power plants of 4.41 MW_p and 8.85 MW_p capacities. The land requirement is 22.07 acres and 44.25 acres. There is one category-4 feeder which supplies electricity to Indo-Tibetan Border Police Complex as a hot line (independent feeder) for various activities at the complex. This feeder require solar PV power plant of capacity of 0.24 MW_p and land requirement is 1.20 acres. Total electricity supplied from this substation during the year 2014-15 was 82942 MWh. The electricity supplied through AP feeders was 31.37% of the total while electricity supplied through UPS feeders was 44.20%. Electricity supplied to urban areas through category-1 feeder was 24.00 % and category-4 feeder was 0.43 %.

(iii) Substations located in the cities/towns

Number of substations supply electricity to urban areas only. Results for one such substation named ‘DC Complex Ludhiana' have been discussed. The results are shown in Table 4. There are 12 feeders of category-1 supplying electricity for predominantly domestic and commercial purposes while one feeder of category-2 supplies electricity for predominantly industrial purposes.

Total electricity supplied during the year 2014-15 from ‘DC Complex Ludhiana’ substation was 103227 MWh. Out of this 100877 MWh (97.72 %) was supplied through category-1 feeders and 2350 MWh (2.28 %) through category-2 feeders. This means that most of the electricity was supplied through category-1 feeders for domestic and commercial purposes.

Table 3. Proposed distributed captive solar PV power plants connected to grid on 11 KV distribution side for Adda Dakha electric grid substation located near the town.

Grid Substation : 66 KV Adda Dakha						
Sr. No.	**Name of 11 KV feeders**	**Category of feeders**	**Total electricity supplied during 2014-15 (MWh)**	**Proposed capacity of solar PV power plants (MW_p)**	**Land required for solar PV power plants (Acres)**	**Initial investment required to install PV power plants (Crore Rupees)**
1	Adda Dakha	Category 1	13282	8.85	44.25	44.69
2	Ajitsar	Category 1	6621	4.41	22.05	22.27
3	Badowal	AP	3858	2.57	12.85	12.98
4	Bhonar City	UPS	11063	7.38	36.90	37.27
5	Detwal	AP	2776	1.85	9.25	9.34
6	Haveli	UPS	5798	3.87	19.35	19.54
7	I.T.B.P	Category 4	354	0.24	1.20	1.21
8	Issewal (R)	AP	5615	3.74	18.72	18.89
9	Issewal (U)	UPS	5301	3.53	17.67	17.83
10	Jangpur	AP	2988	1.99	9.95	10.05
11	Mohie	AP	2289	1.53	7.65	7.73
12	Mullanpur	AP	3257	2.17	10.85	10.96
13	Pandori	AP	2467	1.64	8.20	8.28
14	Sheller City	UPS	14499	9.67	48.35	48.83
15	Talwandi	AP	2775	1.85	9.25	9.34
		Grand Total	82942	55.29	276.45	279.21
		Total AP	26024	17.35	86.75	87.62
		Total UPS	36661	24.44	122.20	123.42
		Total Category 1	19903	13.27	66.35	67.01
		Total Category 4	354	0.24	1.20	1.21

4.3 Electricity supplied through each substation in Ludhiana district during 2014-15

Table 5 shows the electricity supplied through each of the seventy eight substations in Ludhiana district supplying electricity to rural and urban areas. Total annual electricity supplied through these substations during 2014-15 was 8668620 MWh. Out of this 830990 MWh (9.59%) is supplied through AP feeders and 651933 MWh (7.52%) through UPS feeders to 927 villages in Ludhiana district [15]. This means that the electricity supplied to villages constitutes only 17.11% of the total while 41% people live in villages. Remaining 82.89% of electricity is consumed in urban areas through category 1-4 feeders. Obviously electricity consumed in urban areas is much higher.

Table 4. Proposed distributed captive solar PV power plants connected to grid on 11 KV distribution side for DC Complex Ludhiana electric grid substation.

Grid Substation : 66 KV DC Complex Ludhiana						
Sr. No.	**Name of 11 KV feeders**	**Category of feeders**	**Total electricity supplied during 2014-15 (MWh)**	**Proposed capacity of PV power plants (MW_p)**	**Land required for PV power plants (Acres)**	**Initial investment required (Crore rupees)**
1	ESI	Category 1	2141	1.43	7.15	7.22
2	Ferozegandhi Market	Category 1	5325	3.55	17.75	17.93
3	Ghumar Mandi	Category 1	9868	6.58	32.90	33.23
4	Gulmohar	Category 1	11974	7.98	39.90	40.30
5	Khalsa College	Category 1	12911	8.61	43.05	43.48
6	Mall Road	Category 1	9711	6.47	32.35	32.67
7	Model Gram	Category 1	15552	10.37	51.85	52.37
8	National Road	Category 1	5848	3.90	19.50	19.70
9	Park Plaza	Category 1	2637	1.76	8.80	8.89
10	Railway loco shed	Category 2	2350	1.57	7.85	7.93
11	Sant Isher Singh Nagar	Category 1	11482	7.65	38.25	38.63
12	Sutlej Club	Category 1	8504	5.67	28.35	28.63
13	Stock Exchange	Category 1	4924	3.28	16.40	16.56
		Grand Total	103227	68.82	344.10	347.54
		Total Category 1	100877	67.25	336.25	339.61
		Total Category 2	2350	1.57	7.85	7.93

4.4 Capacity, land requirement and initial investment required for proposed distributed captive PV power plants for Ludhiana district

Table 6 shows the capacity of solar PV power plants to replace 100% of the electricity supplied through each category of feeders. Grid-connected distributed solar captive PV power plants with total capacity of 553.99 MW_p can replace total electricity supplied through AP feeders. The corresponding total land requirement is 2769.95 acres and total investment required is 2797.65 crore rupees. Similarly, total capacity of PV power plants for 100% replacement of electricity supplied through UPS feeders is 434.62 MW_p with corresponding land requirement of 2173.10 acres and investment of 2194.83 crore rupees. Both AP and UPS feeders supply electricity to villages. Total land requirement for AP and UPS feeders for 927 villages of Ludhiana district turns out to be 4943.05 acres i.e. 5.53 acres/village. The average land requirement of 5.53 acres/village is too small as compared to land available in villages. Land is available in plenty in villages and electricity load is distributed. Therefore, large number of distributed captive PV power plants can be installed at different places and connected to feeders at different points along the feeder.

For urban areas electricity is supplied through Category 1-4 feeders. The total capacity of solar PV power plants required to replace category 1, 2, 3 and 4 feeders turns out to be 2033.50, 1501.26, 286.58 and 969.12 MWp respectively. The corresponding land requirement is 10167.50, 7506.30, 1432.90, 4845.60 acres and investment required is 10269.18, 7581.37, 1447.23, 4894.06 crore rupees. Total land required for solar PV power plants for cities and towns of Ludhiana district turns out to be 23952.3 acres. Such large amount of land may not be available near the cities/towns.

Table 5. Electricity supplied from various substations located in Ludhiana district through different categories of feeders during 2014-15

Sr. No.	Name of grid substation	Electricity supplied during 2014-15						
		AP feeders (MWh)	UPS feeders (MWh)	Category 1 feeders (MWh)	Category 2 feeders (MWh)	Category 3 feeders (MWh)	Category 4 feeders (MWh)	Total (MWh)
1	66 KV Adda Dakha	26024	36661	19903			354	82942
2	66 KV Agwar Lopon	13279	6093	35613				54985
3	66 KV Alamgir	22232	37421	21217			24516	105386
4	66 KV Amaltas	2464		80560	13676		13569	110269
5	66 KV April Park				17888		3791	21679
6	66 KV Bahadurke	1857		5257	50268	151		57533
7	66 KV Baho Majra	6283		20778	4837			31898
8	66 KV Balloke	2742	2965	52386			22064	80156
9	66 KV Basant Park			94315	54960		391	149665
10	66 KV Bhagpur	1431		1254	13445	8794	6057	30982
11	66 KV Bhaini Sahib	6696	3680	19490	18170		38027	86063
12	66 KV Billet Factory FP				50292		54	50346
13	66 KV Chandigarh Rd			122579	59250		2641	184470
14	66 KV Chaunta	8382	24237					32619
15	66 KV Chawa	18861	7307	10030	1018		14477	51693
16	66 KV DC Complex			100877	2350			103227
17	66 KV Dhandari				155572	135661	41706	332939
18	66 KV Dholewal			49567	6741		3204	59512
19	66 KV Dugri Phase 2	2457		97598				100055
20	66 KV FP -1			7215	101740	5181	11862	125999
21	66 KV FP Phase -8			18739	85658		13052	117448
22	66 KV G T Rd.			272703	20887			293590
23	66 KV Galib Kalan	15544	25394					40938
24	66 KV Giaspura			34939	212151	2656	135252	384998
25	66 KV Gill Road			223492	2792		3402	229686
26	66 KV Haibowal			159796			15348	175143
27	66 KV Heddon Bet	5560	8601					14161
28	66 KV Heeran	16436	15594	1814				33844
29	66 KV Indra Park FP			28790	152135		10597	191523
30	66 KV Jail Rd.			58435			11175	69610
31	66 KV Jallah	1612		470				2082
32	66 KV Jarg	31542		18958				50500
33	66 KV K							

47	66 KV Raj Guru Nagar			90092			1898	91989
48	66 KV Rasoolpur	28095	18964					47059
49	66 KV Rayiawal	102	109					211
50	66 KV Roomi	32870	28726					61596
51	66 KV Sahnewal	5310		20641	88358	11887	149824	276019
52	66 KV Shajahanpur	13824	15684	504				30012
53	66 KV Shamaspur	14967	6137	402				21506
54	66 KV Sidhwan Bet	26413	29394					55807
55	66 KV Sihar	20572	14265	5951				40788
56	66 KV Singla Cycle Rd.				6231			6231
57	66 KV South City	5219		26589			29	31838
58	66 KV Sudhar	27755	30506	10742				69003
59	66 KV Tajpur Rd.			19547	15686		968	36200
60	66 KV Transport Nagar			100335	52129		8838	161302
61	132 KV Bilaspur	8214	9673	4025				21912
62	132 KV Ghulal	17001	19279	30159	14512		27796	108747
63	132 KV Shamaspur	13567	12278		9908			35753
64	132 KV Sawadi Kalan	28661	18525					47186
65	132 KV Seh	10652		9131	1836			21618
66	220 KV Dhandari -1	3102	4864	18680	88781	10432	59701	185559
67	220 KV Dhandari -2				61997	25698	150939	238635
68	220 KV Doraha	11470	20879	20210	52305	24398	125342	254603
69	220 KV Ferozepur Road			148339			9644	157983
70	220 KV Gaunsgarh	14733	16754	20360	76598	6248	4283	138976
71	220 KV Hambran	19067	16778	477	32330		8259	76910
72	220 KV Ikolaha	22962	6998	3773	8523			42256
73	220 KV Jagraon	18939	14048	67276		6936	2492	109691
74	220 KV Jamalpur			30456		110512	53708	194676
75	220 KV Kohara	6842	8845		164952	16118	13383	210139
76	220 KV Lalton Kalan	18337	9023	33089			91401	151849
77	220 KV Pakhowal	32493	22263	752				55507
78	220 KV Sahnewal	7762	7649	20117	107084		230101	372713
	Grand total	830990	651933	3050256	2251892	429867	1453682	8668620
	Percent (%)	9.59	7.52	35.19	25.38	4.96	16.77	100

It may be noted that electric load in cities is concentrated and cost of land on the periphery of cities/towns is very high. Hence, it is not possible to install distributed captive PV power plants on the periphery of cities/towns. It will be essential to go for utility-scale PV power plants of large capacities away from towns/cities where cheap land is available.

It can be concluded that distributed captive PV power plants of smaller capacities can be installed in rural areas as both sunshine and land are available. But urban areas need large utility-scale solar PV power plants installed at longer distance from cities/towns as large chunk of land required is not available on the periphery and cost of land is very high. In other words, distributed energy source (solar energy) can be used conveniently to meet distributed electric load of distributed villages. Hence, first preference should go to installation of distributed captive solar PV power plants in rural areas.

Table 6. Overall data about distributed captive solar PV power plants for Ludhiana district for 100% replacement of grid electricity

Category of feeders	Electricity supplied during 2014-15 (MWh)	Percent of total electricity supplied (%)	Total proposed capacity of PV plants on given feeders (MW_p)	Total land requirement (Acres)	Total initial investment requirement (Crore rupees)
AP	830990	9.59	553.99	2769.95	2797.65
UPS	651933	7.52	434.62	2173.1	2194.83
Category-1	3050256	35.19	2033.50	10167.5	10269.18
Category-2	2251892	25.98	1501.26	7506.3	7581.37
Category-3	429867	4.96	286.58	1432.9	1447.23
Category-4	1453682	16.77	969.12	4845.6	4894.06

V. CONCLUSIONS

1. Electricity is supplied in rural areas to tubewells for agricultural purposes through AP feeders and to villages for residential and commercial purposes through UPS feeders. Electricity is supplied to urban areas through Category 1-4 feeders for residential, commercial and industrial purposes.
2. Almost 83% of total electricity supplied in Ludhiana district goes to urban areas through category 1-4 feeders, while 17% of the electricity is supplied to rural area through AP and UPS feeders.
3. The annual electricity supplied to distributed tubewells and villages in rural areas is 1482923 MWh (17%) which can be replaced by installing distributed captive PV power plants with total capacity of 988.61 MW_p requiring 4943.05 acres of land.
4. Total land requirement of PV power plants for 927 villages in Ludhiana district is 4943.05 acres. So average land required per village turns out to be 5.33 acres/village. Such amount of land is easily available in villages at much lower cost than urban areas. Hence distributed captive PV power plants can be installed in villages.
5. The annual electricity supplied to urban areas is 7185697 MWh (83%) which can be replaced by installing PV power plants of 4790.46 MW_p capacity requiring 23952.3 acres of land.
6. Large amount of land may not be available for PV power plants near the cities/towns Also, the land on the periphery of cities and towns is very expensive. Hence, it becomes essential to install large scale utility scale power plants far away from cities/towns where cheaper land may be available. However, distributed captive rooftop PV systems can be installed on the roofs of residential, commercial and industrial buildings to partially meet the urban electric load.

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