A REVIEW ON PERFORMANCE EVALUATION OF GRID CONNECTED SOLAR PHOTOVOLTAIC POWER PLANTS IN INDIA

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Abstract— The energy sector goes through a paradigm transit from the typical exhausting energy sources to unpolluted energy sources like solar, wind etc. Becoming a carbon neutral nation is the need of the hour for all the countries. Due to colossal potential of solar energy in India, the Government inducts Jawaharlal Nehru National Solar Mission (JNNSM), with an aspiration of forming India, to pioneer worldwide in solar power. In order to succeed in its journey towards procurement of grid tariff parity, there is a necessity to study the actual performance of grid connected solar Photovoltaic generators in the country. This has urged the authors to review about the performance assessment of various Photovoltaic (PV) sources connected to Indian grid. The authors have elucidated the prevailing conditions of grid connected solar power stations in the Indian soil. An extensive literature review on performance analysis of solar photovoltaic power plants in India has been executed in this paper. This study will be a stepping stone for the researchers to understand the Indian grid connected solar plants, and henceforth help in better planning for their future achievements in solar energy systems.

Index Terms—Performance ratio, Capacity factor, System Efficiency, Array yield, Final yield, System loss.

I. INTRODUCTION

India has ample amount of solar energy by nature itself. Almost all parts of the nation acquire 4-7 kWh of energy per square meter in a day. The incident energy amounts to 5,000 trillion kWh/year. It is assured that, the Nation can tackle its total energy requirements by efficiently harnessing a small fraction of total incident sun's energy [1]. Owing to this mammoth solar power, India has begun the Jawaharlal Nehru National Solar Mission (JNNSM) during January 2010, with an ambition of making India as the pioneer nation across the world in solar energy. This mission aims to achieve 20,000 MW of Grid connected solar power plants by the year 2021-22 initially. But in June 2015, this target is ramped to 100,000 MW (100 GW) [2]. As on 2016, the Solar Photovoltaic (PV) capacity established globally is 303 GW and hence establishing 100 GW by 2022 will be an extremely massive target. It has been reported that, solar PV capacity of at least 75 GW has been added globally in 2016. Figure 1 and Figure 2 highlight the global top ten countries for the Solar PV additions and Solar PV total capacity in 2016 respectively. India holds fourth rank globally in the PV additions for adding about 4.1 GW, and occupies the seventh position among all the countries in total Solar PV capacity during 2016 [3, 4].

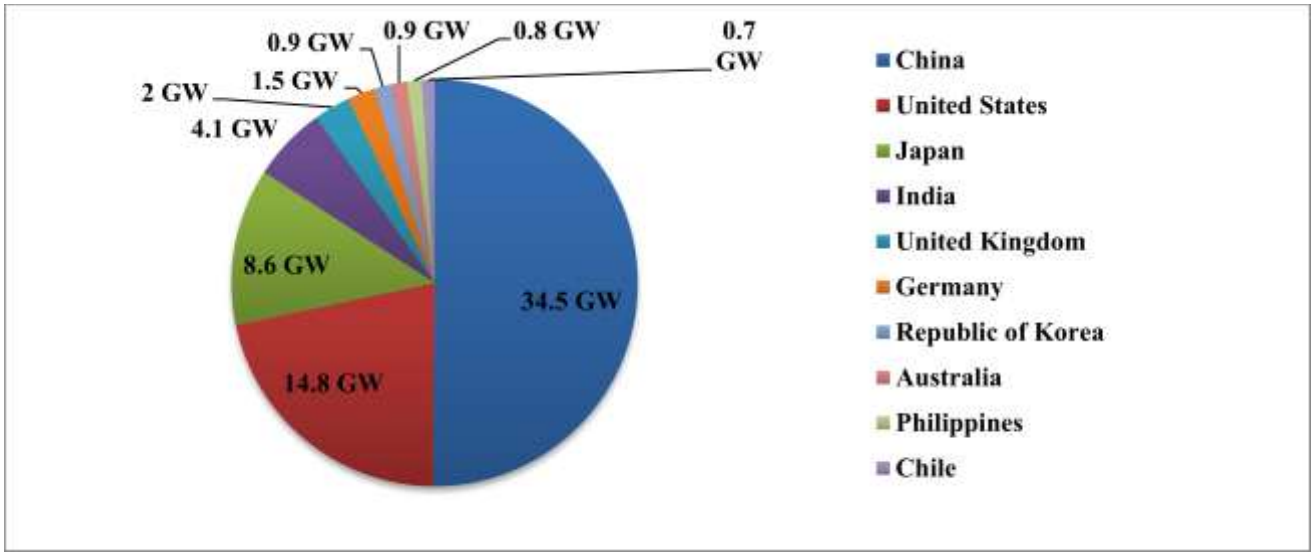

Figure 1 Global Top ten countries based on Solar PV additions in 2016

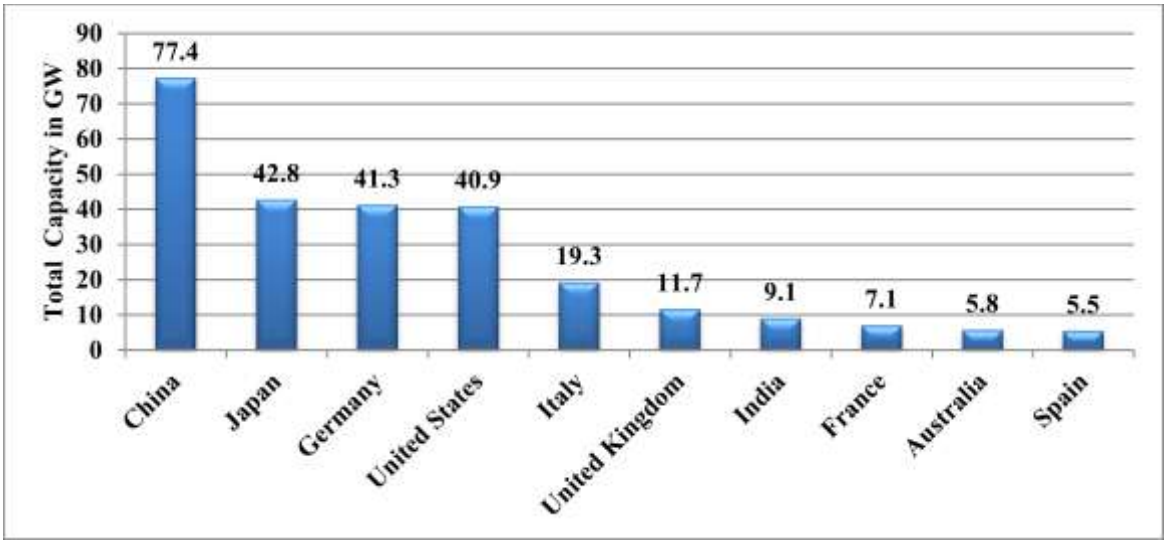

Figure 2 Global Top ten countries based on Solar PV total capacity in 2016

This paper tries to give a detailed statistics of solar energy sector in the Indian soil. Section 2 highlights the prevailing status of Indian grid connected solar power. Commissioning Status of Grid Connected Solar Projects as on October 2017, Installed Capacities of Renewable Energy Sources (RES) as on December 2017, Progress and Cumulative achievements of Indian Power Sectors as on October 2017, Tentative region wise break-up of Solar Power target for 2022, Year-wise targets for Solar Power Projects, and Major Photovoltaic power stations in India are addressed in this section. The performance indices of solar power plant are described in Section 3. An exhaustive review of recent literatures from 2012 onwards on performance analysis of Indian solar photovoltaic power plants is given in Section 4. Finally, the Section 5 concludes the article.

II. CURRENT SCENARIO OF INDIAN GRID CONNECTED SOLAR ENERGY

As of June 2017, India is the proud owner of two numbers of world's top five largest solar power plants, namely Kurnool and Kamuthi Solar Plants. Former project of 1000 MW, situated in Andhra Pradesh ranks third world wide and the latter project of 648 MW lying in TamilNadu ranks fifth globally in their capacities as on 2017 [5]. Ministry of New and Renewable Energy (MNRE) declares that India's solar capacity has shooted up by 370% during the past three years [6].

A. Commissioning Status of Indian Grid Connected Solar Projects

The entire summative capacity of grid connected solar projects as on October 2017 from different states is 15604.76 MW [7]. The installation position of the Nation's Grid connected solar projects as on October 2017 is given in Table 1 [7].

Table 1 Commissioning Status of Grid Connected Solar Projects as on 31.10.2017

S.No	State/Union Territory	Total cumulative capacity till 31-03-17 (MW)	Capacity commissioned in 2017-18 till 31-10-17 (MW)	Total cumulative capacity till 31-10-17 (MW)
1	Andaman & Nicobar	6.56	0.00	6.56
2	Andhra Pradesh	1867.23	271.60	2138.82
3	Arunachal Pradesh	0.27	4.12	4.39
4	Assam	11.78	0.00	11.78
5	Bihar	108.52	33.00	141.52
6	Chandigarh	17.32	0.00	17.32
7	Chhattisgarh	128.86	0.05	128.91
8	Dadar &Nagar	2.97	0.00	2.97
9	Daman & Diu	10.46	0.00	10.46
10	Delhi	40.27	16.95	57.23
11	Goa	0.71	0.00	0.71
12	Gujarat	1249.37	41.81	1291.18
13	Haryana	81.40	110.04	191.44
14	Himachal Pradesh	0.73	0.75	1.48
15	Jammu & Kashmir	1.36	0.00	1.36
16	Jharkhand	23.27	0.10	23.37
17	Karnataka	1027.84	464.54	1492.38
18	Kerala	74.20	14.00	88.20
19	Lakshadweep	0.75	0.00	0.75
20	Madhya Pradesh	857.04	282.95	1139.99
21	Maharashtra	452.37	62.64	515.01
22	Manipur	0.03	1.28	1.31
23	Meghalaya	0.01	0.05	0.06
24	Mizoram	0.10	0.00	0.10
25	Nagaland	0.50	0.00	0.50
26	Odisha	79.42	0.07	79.49
27	Puducherry	0.08	0.00	0.08
28	Punjab	793.95	82.85	876.80
29	Rajasthan	1812.93	433.55	2246.48
30	Sikkim	0.00	0.01	0.01
31	Tamil Nadu	1691.83	20.24	1712.07
32	Telangana	1286.98	1283.45	2570.43
33	Tripura	5.09	0.00	5.09
34	Uttar Pradesh	336.73	171.01	507.74
35	Uttarakhand	233.49	13.40	246.89
36	West Bengal	26.14	7.47	33.61
37	Other/MoR/PSU	58.31	0.00	58.31
	TOTAL	**12288.83**	**3315.92**	**15604.76**

B. Installed Capacity of Renewable Energy Sources in India

The overall installed capacity of Power stations in the country as on 31st December 2017 is 330860.58 MW, from which 60157.66 MW is obtained from Renewable Energy Sources (RES). The various constituents of RES are depicted in Fig. 3[8]. From the figure, it is vivid that around 25% of the total renewable energy of the nation is contributed by Solar.

C. Progress and Cumulative Achievements of Indian Renewable Energy Power Sector

The country shows remarkable growth in Renewable Energy sector. The growth and summative attainments of various grid interactive power schemes under Ministry of New and Renewable Energy (MNRE) as on 31st December 2017 is furnished in Table 2 [9].

Figure 3 Installed capacities of RES in India as on 2017

Table 2 Progress and Cumulative Achievements of Indian Power Sectors as on December 2017

Grid Interactive Power (All Capacities in MW)	2017-18		Cumulative Achievements (as on 31.12.2017)
	Target	Achievement (April – December 2017)	
Wind Power	4000.00	568.71	32848.46
Solar Power – Ground Mounted	9000.00	4492.05	16070.07
Solar Power – Roof Top	1000.00	271.49	982.3
Small Hydro Power	200.00	38.3	4418.35
Bio Power (Biomass & Gasification and Bagasse Cogeneration)	340.00	232.10	8413.80
Waste to Power	10.00	0.00	114.08
Total	**14550.00**	**5602.65**	**62847.06**

It is stated in a PV magazine that, as of November 2017, about 48% share of total installed capacity of Renewable energy is furnished by solar. India has set a milestone by the biggest PV power capacity addition of 5525.98MW in 2017, of which 1.7GW is provided by the roof-top solar [10].

D. Tentative Solar Power Target

Ministry of New and Renewable Energy has framed a tentative solar power target of 99533 MW for the year 2022. The break-up of this target, to be accomplished from all the regions is illustrated in Fig. 4 [11]. It is clear that, around 31%, 28%, 26% and 12% of the total share are targeted for Northern Region, Western Region, Southern Region and Eastern Region respectively. On the other hand, the North Eastern Region and islands (Andaman & Nicobar island and Lakshadweep island) together accounts to 1.24% of the total solar power target.

E. *Comparison of Renewable Power Generation during 2016 and 2017*

Comparison of the total power generation and renewable power generation of the nation during 2016 and 2017 is made in Table 3. The source wise power generation from the Renewable, for the October month of 2016 and 2017 is presented in Fig. 5 [12]. It can be observed that the solar power generation is increased by almost 1000 MU for the October month of 2017, when compared to the same month of previous year. The manifold growth of installed capacity from RES of the country, right from the 6th plan is demonstrated in Fig. 6 [12].

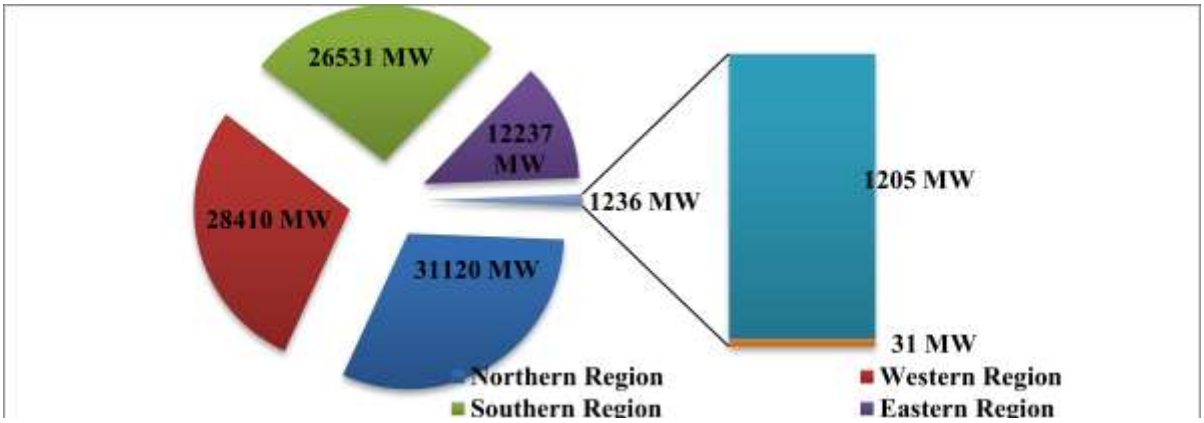

Figure 4 Tentative region wise break-up of solar power target for 2022

Table 3 Comparison of Country's Power generation for 2016 and 2017

Month	Generation from April 2017 to October 2017 (MU)		Generation from April 2016 to October 2016 (MU)		% Growth	
	Generation from RES	Total Generation	Generation from RES	Total Generation	% Growth in Renewable Generation	% Growth in Total Generation
April	6932	110092	5082	104427	36.40	5.42
May	8666	115961	6820	106723	27.07	8.66
June	10228	107753	8118	105444	25.99	2.19
July	12928	110840	9554	105996	35.32	4.57
August	10857	105463	9571	104808	13.44	0.62
September	7516	105588	8279	104020	-9.22	1.51
October	6564	109182	6274	106053	4.62	2.95

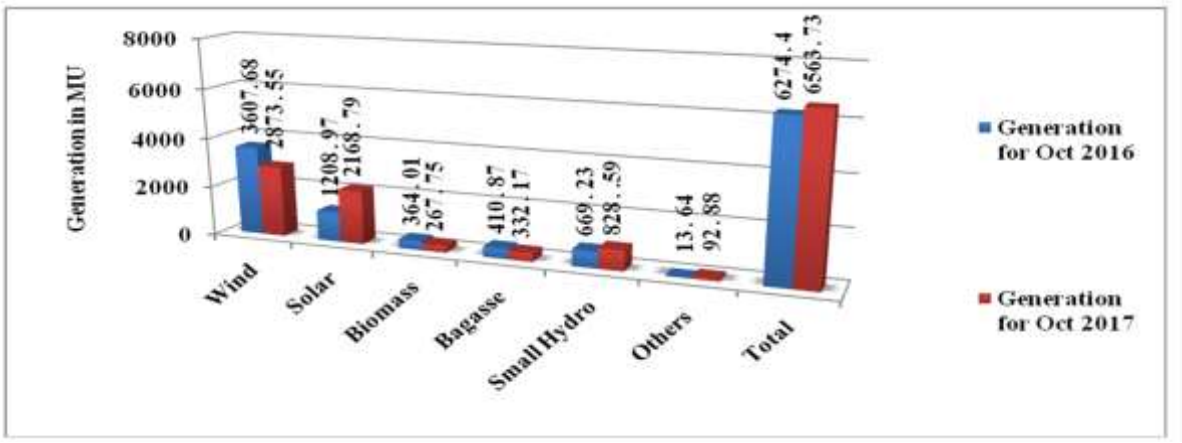

Figure 5 Source wise power generation from the renewables for the October 2016 and 2017

F. Year-Wise targets of National Solar Mission

The year-wise targets of National Solar Mission up to 2022, to accomplish its desire of establishing 40 GW of Rooftop solar projects and 60 GW of large and medium scale projects, together contributing 100 GW, are listed in Table 4 [13].

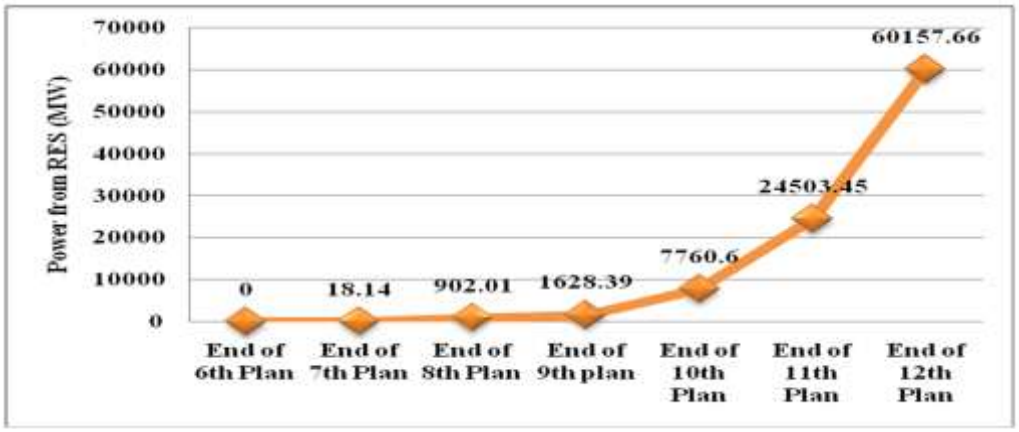

Figure 6 Growth of Installed Capacity from RES

Table 4 Year wise targets for Solar power projects

Year	Roof Top Solar Power Projects (MW)	Ground Mounted Solar Power Projects (MW)
2015-2016	200	1800
2016-2017	4800	7200
2017-2018	5000	10000
2018-2019	6000	10000
2019-2020	7000	10000
2020-2021	8000	9500
2021-2022	9000	8500
Total	**40000**	**57000**

G. Major Solar Power Plants in India as on 2017

Several extensive solar power generators of the nation with at least 10 MW capacity are given in Table 5[14- 16]. Bhadla solar plant of Rajasthan has obtained a minimum solar tariff of INR 2.044/unit [17].

Table 5 Some of the major solar power plants in India

Plant	State	Capacity (MW)	Commissioned Date
Tata Power Solar Systems (TPS), Rajgarh	Madhya Pradesh	50	March 2014
Jalaun Solar Power Project	Uttar Pradesh	50	January 2016
Green Energy Development Corporation (GEDCOL)	Odisha	50	2014
GEDCOL	Odisha	48	2014
Dhirubhai Ambani Solar Park, Pokhran	Rajasthan	40	April 2012
Bitta Solar Power Plant	Gujarat	40	January 2012
Rajasthan Photovoltaic Plant	Rajasthan	35	February 2013
Welspun, Bathinda	Punjab	34	August 2015
Moser Baer, Patan district	Gujarat	30	October 2011
Lalitpur Solar Power Project	Uttar Pradesh	30	2015
Mithapur Solar Power Plant	Gujarat	25	January 2012
GEDCOL	Odisha	20	2014
Kadodiya Solar Park	Madhya Pradesh	15	2014
Waa Solar Power Plant, Surendranagar	Gujarat	10	December 2011
Ushodaya Project, Midjil	Telangana	10	December 2013
Sunark Solar	Odisha	10	2011
Sharda Construction, Latur	Maharashtra	10	June 2015
RNS Infrastructure Limited, Pavagada	Karnataka	10	2016
NTPC	Odisha	10	2014
Green Infra Solar Energy, Rajkot	Gujarat	10	November 2011
Bolangir Solar Power Project	Odisha	10	2011
Azure Power, Sabarkantha	Gujarat	10	June 2011
Kurnool Ultra Mega Solar Park	Andhra Pradesh	1000	March 2017
Bhadla Solar Park	Rajasthan	2255 (planned)	February 2017

Table 5 Continued

Plant	State	Capacity (MW)	Commissioned Date
Kamuthi Solar Power Project	Tamil Nadu	648	September 2016
Charanka Solar Park	Gujarat	221	April 2012
Welspun Solar MP Project	Madhya Pradesh	151	February 2014
ReNew Power, Nizamabad	Telangana	143	April 2017
Sakri Solar Plant	Maharashtra	125	March 2013
NTPC Solar Plants		110	2015
Welspun Energy, Phalodhi	Rajasthan	50	March 2013

III. PERFORMANCE PARAMETERS OF GRID CONNECTED SOLAR POWER PLANT

Grid connected Solar PV generation enables the efficient usage of the harnessed solar energy. Nevertheless the technical facets of PV generator and the utility side should be fulfilled simultaneously, to enhance the reliability of the grid [18]. For the purpose of investigating the grid connected PV systems, the International Energy Agency (IEA) has set up some specifications like performance ratio, capacity factor, energy output, array yield, reference yield, final yield, system efficiency, module efficiency, inverter efficiency, and energy loss which includes both the system loss and capture loss [19-21]. The disparate systems with varying size and locality can be correlated by using the normalized performance indictor values [22]. These performance evaluators are as follows [19-28]:

A. Performance Ratio (PR)

It is one of the essential indicators for assessing the performance of PV systems. It is defined as the ratio of final yield to reference yield. It symbolizes the reliability and efficacy of the PV system. It indicates the closeness with which the PV system operates in real operating conditions to that of ideal performance. Systems with disparate capacities, mounting structures, and locations can be compared with this parameter. It is the quantity of energy that can be injected to the grid after the deduction of losses. It is expressed in percentage. It is also known as 'Quality Factor'.

B. Capacity Factor (CF)

It is in fact found by dividing the actual annual energy output, by the amount of energy which the solar PV plant would generate, if it is run at full rated power for all the hours of a day in a year. This factor denotes the energy delivered by a PV plant.

C. Array Yield (Y_A)

It is nothing but expressing the PV array's output over a specified period (day, month or year) as a fraction of its rated power.

D. Final Yield (Y_F)

It is expressing the AC energy produced by the PV power plant for a specified term (day, month or year) as a fraction of its rated DC power at Standard Testing Conditions (STC). It is also called as 'yield factor'.

E. Reference Yield (Y_R)

Division of total in plane solar insolation H_t (kWh/m^2) by the reference irradiation G (1kW/m^2) is called as Reference Yield. It expresses the number of maximum sun-hours in a day.

F. Array capture Loss (L_C)

It is found by subtracting array yield from the reference yield. They are caused due to solar PV array losses.

G. System Loss (L_S)

The difference between array yield and final yield is known as System loss. They are caused as a result of discontinuous operation of inverter.

H. System Efficiency(η_{sys})

It is the product of PV module efficiency and inverter efficiency.

I. Inverter Efficiency(η_{inv})

It is otherwise called as 'conversion efficiency'. It is the expression of generated AC power of inverter as a fraction of generated DC power of the PV array system.

IV. LITERATURE REVIEW

Several tasks for evaluating the performance of Solar PV plant are framed by the International Energy Agency (IEA). Due to non association of India with IEA, the performance criteria of Indian Solar Photovoltaic power plants as per IEC Standard 61724 are not obtainable. Hence it is imperative to document the performance of the same, to understand their existing operating conditions, and thereby appropriate steps can be taken to enhance their performance [19, 25]. This has motivated the authors to do an aggressive literature study on the performance of the Solar PV plants in India and it has been discussed in Table 6 [18-47].

Table 6 Brief Summary of Reviewed articles

Authors	Capacity	Plant location	Monitoring Period	PV Technology	tilt angle	Observed Results
Mandal et al. [18]	1 kWp	School of Energy Studies, Jadavpur University, Kolkatta.	1 month (Oct 2015)	-	25°	1.Average energy generated is 3-4 kWh/day. 2.Overall system efficiency varies between 12.3% and 18.42%.
Sundaram et al. [19]	5 MWp	Sivagangai District, Tamilnadu.	1 year (May 2011-Apr 2012)	Thin film	10°	1. RET screen plus software is used used for simulation. 2. 8495296.4 kWh is the total annual energy generation. 3. Annual average daily array Yield, Corrected reference yield and Final yield are 5.46 h/d, 5.128 h/d, and 4.810 h/d respectively. 4. Performance ratio is 89.15%. 5. Overall average daily capture loss is 0.384 h/d and the system loss is 0.65 h/d. 6.Annual average PV module and System efficiencies are 6.08% and 5.08% respectively. 7.Statistical validators such as Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) are evaluated , whose overall annual average values are varying from 0.04 to 4.57 and from -0.0013 to 0.2425 respectively. 8.Monthly average Capacity factor is high in September amounting to 22.9% , and less in December yielding 16.17%.
Kumar et al. [20]	10 MWp	National Thermal Power Corporation (NTPC),	1 year (Apr 2014-Mar 2015)	Poly crystalline	seas -onal tilt	1. PVsyst and PV-GIS softwares are used for simulation. 2. Annual energy generated is

		Ramagundam, Telangana.			Nov-Feb 33.75° May-Aug 3.75° Sep, Oct, Mar, Apr 18.75°	15798.192 MWh. 3. Efficiency of panel is 14.06%. 4. Its Capacity Utilization Factor (CUF) is 17.68%. 5. Annual Performance Ratio is 86.12%. 6. The variation of Final yield is in the range of 1.96 to 5.07h/d. 7. Normal productions recordings of Capture loss, System loss and Final yield are 1.23 kWh/kWp/day, 0.13 kWh/kWp/ day and 4.36 kWh/kWp/day respectively. 8. Efficiency of PV array is 13.3%. 9. The actual energy generation is compared with simulated results of PVsyst and solarGIS.
Sharma et al. [21]	190 kWp	Khatkar-Kalan, Punjab	1 year (Jan 2011-Dec 2011)	Poly crystalline	25°	1. PVsyst software is used for Simulation. 2.The annual average performance ratio, capacity factor and System efficiency are 74%,

Table 6 Continued

Authors	**Capacity**	**Plant location**	**Monitoring Period**	**PV Technology**	**tilt angle**	**Observed Results**
Sharma et al. [21] Continued						9.27% and 8.3% respectively. 3. Reference yield fluctuates between 2.29 h/d to 3.53 h/d. 4. The variation of Final yield is in the range of 1.45 to 2.84 h/d. 5. The energy supplied by the plant is 154.43 MWh.
Singh et al. [22]	43kWp	Indian Institute of Technology, Jodhpur, Rajasthan.	3 years (Jul 2011-Jul 2014)	Amorphous Silicon thin-film	-	1. Module efficiency is 6.6% . 2. Performance ratio lies in the range of 0.52-0.81. 3. In all the three years, Monthly total energy produced varies approximately from 3500 kWh to 7000 kWh, whereas the monthly specific yield approximately lies in the range of 90 – 165 kWh/kWp. 4. PVUSA rating is 0.83-0.88. 5. Year-wise Total yield fluctuates between 38000 kWh to 79000 kWh approximately during the period of observation.
Dobaria et al. [23]	5.05 kWp	Darshan Institute of Engineering and Technology, (DIET) Rajkot, Gujarat.	1 year (Dec 2012-Nov-2013)	Poly crystalline	15°	1.Total energy generated per annum is 8265 KWh. 2. Measured energy yield is 1636 kWh/kWp. 3. Array yield varies from 3.1 h/d to 5.7 h/d. 4. Final yield varies from 2.96 h/d to 5.43 h/d . Its Annual average final yield is 4.49 h/d.. 5. Reference yield varies from 4.22 h/d to 7.22 h/d. 6. Performance ratio is in the range of 0.68 to 0.83 with an average value of 0.74. 7. Annual average Array capture Loss, system loss and specific yield are 1.35 h/d, 0.23h/d and 4.49 h/d respectively.
Tripathi et al	1 MWp	Gandhinagar,	1 year	Amorphous	22.22°	1.Peformance ratio of mc-Si plant

[24]	(2 Nos. of 500 kWp each)	Gujarat.	(Jan 2012-Dec 2012)	Silicon (a-Si) and multi crystalline (mc-Si)		and a-Si plant ranges from 57.1 to 93.14 and from 53.72 to 87.64 respectively. 2.Gross energy generated per year for mc-Si and a-Si plants are 25503 kWh and 23996.5 kWh respectively. 3.Array Yield of mc-Si plant varies between 2.92 h/d to 5.46 h/d whereas that of a-Si plant lies in the range of 2.98 h/d to 5.05h/d. 4.Annual average Final Yield of mc-Si and a-Si plants are 4.25h/d and 3.99 h/d respectively. 5.The annual average capture loss and annual average system loss for mc-Si plant are found to be 1.21 h/d and 0.22 h/d respectively.

Table 6 Continued

Authors	**Capacity**	**Plant location**	**Monitoring Period**	**PV Technology**	**tilt angle**	**Observed Results**
Tripathi et al [24] Continued						6.The annual average capture loss and annual average system loss for a-Si plant are found to be 1.37 h/d and 0.31 h/d respectively.
Padmavathi et al. [25]	3 MWp	Yalesandra, Kolar district, Karnataka	2 years (2010 and 2011)	Mono crystalline	15°	1.Performance ratio is less than 0.6 for the months from August to November of 2010,whereas it is more than 0.6 in 2011. 2.Capacity Factor in 2010 is 12.38% and in 2011, it is 15.69%. 3.Annual total energy generated is 1372.6 kWh/kWp. 4.Annual average daily Final Yield, Array yield and Reference yield are 3.73, 3.98 and 5.36 kWh/(kWp-day) respectively. 5. The efficiency of PV array varies from 10.1% to 13.25%.
Kumar et al. [26]	20 kWp	Bharat Heavy Electricals Limited (BHEL), Tiruchirappalli, Tamiladu.	1 year (Jan –Dec)	Poly crystalline	-	1. Total energy generated by the system is 30140 kWh. 2. Performance Ratio is about 82%. 3. Annual average Capacity Factor is 17.2%. 4. Efficiency of PV module varies between 10.14% and 12.6%. 5. A Comprehensive economic analysis of the plant is done by considering various factors like Plant performance, government subsidies, tax credits etc.
Sharma et al. [27]	11.2kWp	Siksha 'O' Anusandhan University, Bhubaneswar, Odisha.	1 year (Sep 2014-Aug 2015)	Poly crystalline	21°	1.Total energy injected to the grid is 14.96 MWh. 2. Efficiencies of PV module, inverter and system are 13.42%, 89.83% and 12.05% 3. Performance ratio obtained is 0.78. 4. The annual average monthly final yield, reference yield and array yields are 3.67, 4.73 and

						4.09 h/d respectively. 5. A reduction of 14.661 tonnes of CO_2 /annum is achieved. 6. The annual monthly average Capacity Utilization Factor (CUF) is 15.27%.
Vasisht et al. [28]	20 kWp	Indian Institute of Science (IISc) Bangalore, Karnataka.	2 years (Apr 2013-Jun2015)	Poly crystalline	13°	1. The CUF is 16.5%. 2. Average PR is 85%. 3. Net annual yield and annual average daily specific yield are 28.9 MWh and 4.1 kWh/kWp. 4. Total yield is 70 MWh. 5.Reduction of 23 tonnes CO_2 emission /annum into atmosphere is achieved.

Table 6 Continued

Authors	**Capacity**	**Plant location**	**Monitoring Period**	**PV Technology**	**tilt angle**	**Observed Results**
Singh et al. [29]	58 kWp	Indian Institute of Technology, Jodhpur, Rajasthan.	3 years (Jul 2011-Jul 2014)	multi crystalline	-	1. Module efficiency is 13.6% . 2. Performance ratio lies in the range of 0.16-0.98. 3. In all the three years, Monthly Total Yield lies in between 1000 kWh to 10000 kWh and monthly Specific Yield varies approximately from 25 kWh/kWp to 165 kWh/kWp. 4. PVUSA rating is 0.80-0.89. 5. Year-wise Total yield fluctuates between 48000 kWh to 90000 kWh approximately during the period of observation.
Kumar et al. [30]	100 kWp	Educational Institute, India.	1 year (Jan-Dec)	Poly crystalline	-	1. PVsyst V6.52 software is used for simulation. 2. Energy generated and energy injected into the grid are 165.38 MWh and 161.6 MWh respectively. 3. Annual performance ratio is 80%. 4. Annual average efficiency of PV array and the system are13.17% and 12.87% respectively. 5. Normalized Capture loss, System loss and Useful energy are 1.0 kWh/kWp/day, 0.1 kWh/ kWp/day and 4.42 kWh/kWp/day respectively.
Kandasamy et al. [31]	1 MWp	Tuticorin, TamilNadu.	1 year (Jan-Dec)	Mono crystalline	9°	1. PVsyst 5.59 software is used for simulation. 2. Generated total energy is 1565883 kWh . 3. Total amount of energy injected into the grid is 1522909 kWh. 4.Transposition factor is 0.9992. 5. Efficiency of PV array and System are 15.55% and 11.46% respectively. 6. Module quality loss, Module Mismatch loss, Ohmic wiring loss, and total inverter loss are calculated to be 882.64 kWh/ Year, 35280 kWh/year, 14814 kWh/year and 95068 kWh/year respectively. 7. Comparision of the Tuticorin site with Sivakasi, Sivagangai

						and Madurai sites is made. 8.Energy production from Tuticorin, Sivakasi, Sivagangai and Madurai sites are 1523 MWh/year, 1398 MWh/year, 1335 MWh/year, and 1414 MWh/year respectively. 9.Peformance ratios of Tuticorin, Sivakasi, Sivagangai and Madurai sites are 0.749, 0.775, 0.753, and 0.752 respectively.

Table 6 Continued

Authors	**Capacity**	**Plant location**	**Monitoring Period**	**PV Technology**	**tilt angle**	**Observed Results**
Ramoliya [32]	1 MWp	Shapur village, Gujarat.	1 year (Jan-Dec)	Poly crystalline	22°	1. PVsyst 5.41 software is used for simulation. 2. Out of 1449870 KWh of energy generated, 1416980 KWh of energy is injected to the grid. 3. The average performance ratio is 0.764. 4. Module quality loss, Module Mismatch loss, Ohmic wiring loss, and total inverter loss are calculated to be 802.14 kWh/ Year, 32055 kWh/year, 15476 kWh/year and 33326 kWh/ year respectively 5. The average efficiency of the system is 11.02% and that of PV array is 14.60%. 6. Normalized value of the array Yield and Final Yield are 0.01 kWh/kWp/day and 3.88 kWh/kWp/day respectively.
Mitavachan et al. [33]	3 MWp	Yalesandra, Kolar district, Karnataka	1 year (Jan 2010-Dec 2010)	Mono crystalline	15°	1.About 3.34 million kWh of energy is generated from which 3.30 million kWh is fed to the Grid. 2.Annual Plant Load Factor (PLF)
Yadav et al. [34]	1 kWp	Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur, Himachal Pradesh.	1 year (Jan-Dec)	Poly crystalline	9° and 46° (for summer and Winter)	1. PVsyst software is used for simulation. 2. Performance ratio is 0.724. 3. PV module efficiency is 11.76%. 4. Effective array energy output is 1478.2 kWh , from which 1356.0 kWh of energy is fed to the load.
Berwal et al. [35]	50 kWp	Deenbandhu Chhotu Ram University of Science & Technology, Murthal, Haryana.	7 months (Jun-Dec)	Poly crystalline	30°	1. Power generation varies from 3545.9 kWh/month to 7189.4 kWh/month. 2. Generation is more than 5200 kWh/month. 3. Performance Ratio lies between 0.523 and 0.874. 4. This plant reduces GHG emissions amounting to 4070 Kg/month which is nearly 1221 tons of carbondioxide. 5. Payback period with government subsidy is estimated to be 5.7 years with Internal Rate of Return (IRR) of 16.97%. 6. Payback period without government subsidy is found to be 10.3 years with Internal Rate

						of Return (IRR) of 8.22%. 7. Standards applicable for PV module, structures, inverters, switchboards, DC cables, LV AC cables are listed as Annexure.

Table 6 Continued

Authors	**Capacity**	**Plant location**	**Monitoring Period**	**PV Technology**	**tilt angle**	**Observed Results**
Shukla et al. [36]	110 kWp	Maulana Azad National Institute of Technology (MANIT) Bhopal, MadhyaPradesh.	1 year (Jan –Dec)	Four technologies Crystalline Silicon (c-Si), Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), Copper Indium Selenide (CIS).	23°	1. Solargis software is used for Simulation. 2. System energy yield for c-Si, a-Si, CdTe and CIS modules are 1483 kWh/kWp, 1646 kWh/kWp, 1593 kWh/kWp, and 1513 kWh/kWp respectively. 3. Annual average energy production for c-Si, a-Si, CdTe and CIS modules are 163.1 MWh, 181.1MWh, 175.3 MWh and 166.5 MWh respectively. 4. Performance ratios ranges from 71.6% (c-Si module) to 79.5% (a-Si module).
Matiyali et al. [37]	400kWp (Proposed Plant)	Dhalipur, Uttarakhand.	1 year (Jan –Dec)	GB72P6-240 module	30°	1. PVsyst 6.4.1 is used for performance analysis of the system. 2. Performance ratio obtained is 78.1%. 3. Final yield varies from 3.14 kWh/kWp/d to 5.65kWh/kWp/d. 4. Value of simulated array Capture loss, System loss, and Final yield are 18.3%, 3.6% and 78.1% respectively.
Bharathkumar et al. [38]	5 MWp	Shivanasamudra, Mandya District, Karnataka.	7 months (Nov 2013-May 2014)	Mono crystalline	15°	1. PVsyst software is used for Simulation. 2. The actual energy generation varies from 528.3 MWh/month to 770.9 MWh/month. 3. Final yield varies from 1.96 to 5.07 h/d. 4.The annual value of Performance Ratio is 67.36%. 5. Capacity Utilization Factor (CUF) is 19%. 6. The average yearly energy output is calculated to be 7416.12 MWh. 7. The efficiency of the solar panel is 14.3%.
Bano et al. [39]	1 MWp	Rajasthan Renewable Energy Corporation Limited (RRECL), Phagi, Jaipur, Rajasthan.	3 years (2013, 2014, 2015)	Poly crystalline	26°	1. Performance parameters are calculated by using three Softwares namely Excel sheet, PV syst, and System Advisory Model (SAM). 2. The efficiency of the solar panel is 15-16%. 3. The energy generated per per annum by Excel sheet varies from 1541 MWh to 1641 MWh. 4. From the computations by Excel sheet, the ranges of Reference yield, Final yield, Performance ratio and Capacity

						Utilization Factor are

Table 6 Continued

Authors	Capacity	Plant location	Monitoring Period	PV Technology	tilt angle	Observed Results
Bano et al. [39] Continued						5.60-5.70 h/d, 3.8-4.4 h/d, 74.24% -78.26%, and 17.59%-18.73% respectively. 5. From the PVsyst software, it is found that the total energy generated from the PV array is 1625.5 MWh 6.The annual average Performance ratio, array loss, system loss, and Final yield obtained through PVsyst are 78.8%, 1.02 kWh/kWp/day, 0.18 kWh/kWp/day, and 4.44 kWh/kWp/day respectively. 7. From the SAM software, it is found that the annual energy generation, Capacity Utilization Factor and Performance ratio are 1704 MWh, 19.4% and 77.0% respectively. 8. Levelized Electricity Cost (LEC) varies from 11.33 Rs./kWh to 12.06 Rs./kWh.
Shivalkar et al. [40]	15 kWp	Reliance Energy Management Institute, Mumbai.	1 year	Poly crystalline	-	1. Overall PR is greater than 70%. 2. Energy generation is 22500 units /annum. 3.Reduction of 19575Kg of CO_2 emission /annum into atmosphere is achieved. 4. Annual saving amounts to Rs.259200 and the payback period is found to be 4.63 years. 5. Its unit cost is calculated to be Rs.3.98.
Kumar et al. [41]	80 kWp	GRT IET Campus, Thiruthani, TamilNadu.	6 months (Apr 2015-Sep 2015)	mono crystalline	30°	1.Efficiency of PV panel is 15.53%. 2. Transformer less grid tied String inverter is used in this Plant. 3.Total energy amounting to 64182.86 kWh is generated by the solar plant. 4.Energy saving per year is 204,400 kWh. 5. The average final yield and reference yield are 802.285 h/d and 957.09 h/d respectively. 6.Performance ratio, system efficiency and capacity factor are 83.82%, 4.16% and 18.26% respectively. 7. Payback period is found to be 9 years and 4 months. 8. Cost reduction /year is calculated to be 17,37,400 INR 9. About 102,200 tonnes of CO_2 emission is reduced in a year.
Sukumaran et al. [42]	2 MWp (Proposed	Raja Bhoj International	1 year (Jan –Dec)	Poly crystalline	23°	1. Performance analysis is made by using PV SISIFO

Table 6 Continued

Authors	Capacity	Plant location	Monitoring Period	PV Technology	tilt angle	Observed Results
Sukumaran et al. [42] Continued	Plant)	Airport, Bhopal, Madhya Pradesh.				simulation tool. 2. Plant can generate 2733.122 MWh/annum. 3. Monthly average energy yield and PR are 113.88 kWh/kWp and 85.54% respectively. 4. Annual energy yield and Performance ratio are 1367 kWh/kWp and 85.54% Respectively. 5. CUF lies in the range of 6.65% to 22.64%. Average CUF of the plant is 15.82%. 6. Pay back period is 4.56 years. 7. It can mitigate the emission of CO_2 of about 56,029 tonnes in its life time of 25 years.
Pundir et al. [43]	1816 kWp	IIT Roorkee, Uttarakhand.	1 year (Apr 2014-Mar 2015)	Poly crystalline	-	1. Module efficiency is 13.8%. 2. Final yield and reference yield are 1213.1 h/d and 1905.3 h/d respectively. 3.Performance ratio, capacity factor and system efficiency are 0.6368, 0.1385 and 0.0877 respectively. 4. Total Energy generation is 2202907 kWh/annum. 5. Unit generation cost is about Rs. 8.5 /unit (without subsidy), and it is Rs.0.85/unit (with subsidy). 6. Payback period is found to be 7.5 years. 7. CO_2 reduction /annum is 2464 tons.
Khanna et al. [44]	150 kWp	NorthCap University(NCU) Gurgaon, Haryana.	4 months (Jul 2015-Oct 2015)	Poly crystalline	25°	1. Generated output energy vary from 204 kWh/month to 726.8 kWh/month.
Omkar et al. [45]	50 kWp	Shri Vishnu Educational Society, Bhimavaram, AndhraPradesh.	1 month (Oct 2014)	Poly crystalline	-	1. Efficiency of PV module is 15.54%. 2. Average daily energy output is 175.183 kWh. 3. Average daily performance Ratio is 69.30%. 4. Average annual capacity factor is 5.822%. 5. Final yield fluctuates between 0.8 and 4.6 kWh/kW/day. 6. Reference yield varies from 1.023 to 6.55 kWh/kW/day.
Krishniya et al. [46]	1 MWp	3 places Jodhpur, Kolkata, Chennai.	1 year (Jan-Dec)	-	30°	1. Simulation is done using PVsyst 5.74. 2. Energy generated from PV array of Jodhpur plant is 1664.7 MWh, from which 1630.3MWh is fed to grid. 3. Energy generated from PV array of Kolkata plant is 1419.0 MWh,

Table 6 Continued

Authors	Capacity	Plant location	Monitoring Period	PV Technology	tilt angle	Observed Results
Krishniya et al. [46] Continued						from which 1388.7MWh is fed to grid. 4. Energy generated from PV array of Chennai plant is 1441.2MWh from which 1410.5MWh is fed to grid. 5. Normalized productions of Array loss, system loss and Final yield for Jodhpur plant are 1.4kWh/kWp/day, 0.09 kWh/kWp/day, and 4.46 kWh/ kWp/day respectively. 6. Normalized productions of Array loss, system loss and Final yield for Kolkata plant are 1.17 kWh/kWp/day, 0.08 kWh/kWp/day, and 3.8 kWh/ kWp/day respectively. 7. Normalized productions of Array loss, system loss and Final yield for Chennai plant are 1.22 kWh/kWp/day, 0.08 kWh/kWp/day, and 3.86 kWh/ kWp/day respectively. 8. Per unit cost of energy for Jodhpur, Kolkatta and Chennai are Rs.5.53, Rs.6.49 and Rs. 6.39 respectively.
Verma et al. [47]	20 MWp	NSL group, Shivlakha, Gujarat	1 year	Amorphous Silicon Thin film	20°	1. Simulation is done using PVsyst version 5. 2. Performance ratio of the plant is 80.13%.

V. CONCLUSION

India shows a steep progressive growth in the solar energy sector. Currently, the nation is one among the top ten countries in Solar Photovoltaic additions and total commissioned solar photovoltaic capacities. Ministry of New and Renewable Energy informs that, about 15.60 GW capacities have been added to Indian solar grid as of October 2017. The nation aims for 100GW of power to be harnessed from the sun by 2022. Hence to achieve this huge target, an in-depth knowledge of existing status of Indian grid connected solar power systems is indispensable. This paper portrays a voluminous review of performance evaluation of grid connected Solar Photovoltaic plants in India. Firstly, the present day conditions in Indian grid connected solar power are discussed.

Several factors, including the installation status of grid connected solar projects as of 2017, Inducted capacity of Renewable Energy Sources in India as of 2017 have been listed by the authors. Also the progress and growth of Indian renewable energy power sector with an emphasis on solar energy power sector, approximate solar power targets for different regions up to 2022, detailed year-wise targets of National Solar mission, and few of the major Solar power plants of India are addressed. Later, the parameters influencing the performance of the solar power plants have been explained. Then the recent articles on performance analysis of grid connected solar power plants in India, published from the 2012 year onwards have been reviewed and its summary is presented in this paper.

Hence this review article will definitely help the researchers, engineers, and academicians to take appropriate steps in improving the performance of Indian grid connected solar power systems, thereby the dream of achieving 100 GW of solar power by 2022, may come into reality in near future.

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