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A Review on Feasibility and PerformanceAnalysis of Grid Connected Solar Photovoltaic Power Plants in India

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Abstract— *The energy sector goes through an epitome transit from typical exhausting energy sources to clean energy resources like solar, wind etc. To become a carbon neutral country is the need of the hour for all the nations. Due to stupendous potential of solar energy in India, the Government initiated Jawaharlal Nehru National Solar Mission (JNNSM), with an inspiration of forming India, to innovate worldwide in solar power. In order to succeed in its intention towards procurance of grid tariff parity, there is a requirement to study the actual performance of grid connected solar Photovoltaic generators in the nation. This has cheered the writers to follow up about the performance appraisal of various Photovoltaic (PV) reservoir connected to Indian grid. The writers have crystalized the prevalent conditions ofgrid connected solar power stations in the Indian stain. An encompassing literature follow up on performance analysis of solar photovoltaic power plants in India has been carried out in this paper. This study should be a stepping stone for the researchers to realize the Indian grid connected solar plants, and henceforward help in improved planning for the future accomplishments in solar energy arrangements.*

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I. INTRODUCTION

India has plentiful quantity of solar energy by nature itself. Almost everywhere in the nation inherit 4-7 kWh of energy per square meter in a day. The incidental energy quantity to 5,000 trillion kWh/year. It is insured that; the country can harness its sum up energy demands by expeditiously tackling a minor fraction of sum up incident sun's energy. Owing to this gigantic solar power, India has started the Jawaharlal Nehru National Solar Mission (JNNSM) in January 2010, with an aspiration of making India as the initiator nation across the world in solar energy. This mission has an objective to attain 20,000 MW of Grid connected solar power plants by the year 2021-22 initially. But in June 2015, this objective is raged to 100,000 MW (100 GW). As on 2016, the Solar Photovoltaic (PV) capability naturalized globally is 303 GW and hence accomplishing 100 GW by 2022 will be a highly massive aim. It has been reputed that, solar PV capability of at least 75 GW has been included globally in 2016. Figure 1 and Figure 2 spotlight the global top ten countries of Solar PV summations and Solar PV total capability in 2016 respectively. India has fourth rank globally in the PV summations for adding about 4.1 GW, and occupies the seventh rank among all the nations in total Solar PV capacity in 2016.

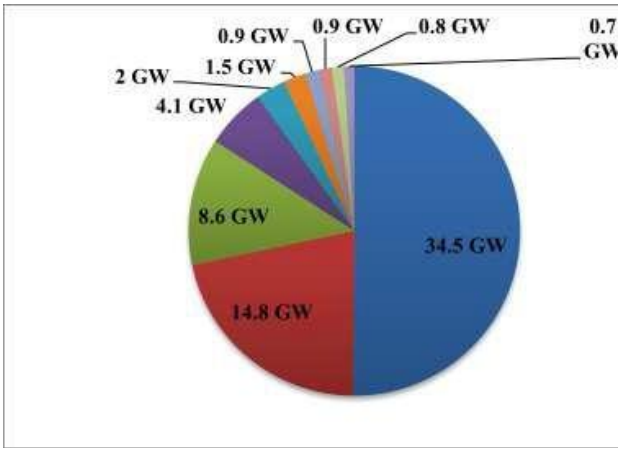

Figure 1 Global Top ten countries based on Solar PV summations in 2016

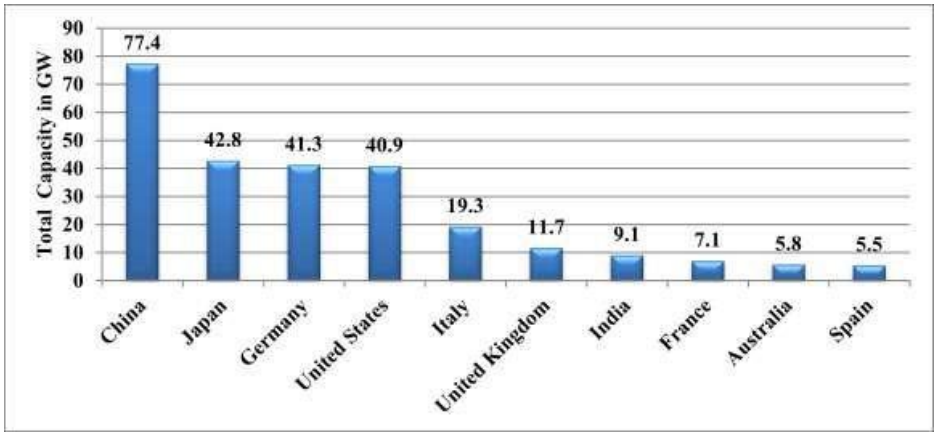

Figure 2 Global Top ten countries based on Solar PV overall capacity in 2016

This paper tries to give a detailed census of solar energy sector in India. Section 2 spotlights the prevalent condition of Indian grid connected solar power. Commission Status of Grid Connected Solar Projects as on October 2017, Installed Capacities of Renewable Energy Sources (RES) as on December 2017, Advancement and Accumulative accomplishments of Indian Power Sectors as on October 2017, Provisional area wise detachment of Solar Power objective for 2022, Year-wise aims for Solar Power Projects, and Major Photovoltaic power stations in India are addressed in the section. The execution indices of solar power plant are explained in Section 3. A thorough audit of recent literatures from 2012 onwards on operation audit of Indian solar photovoltaic power plants is given in Section 4. Lastly, the Section 5 concludes the article.

II. CURRENT SCENARIO OF INDIAN GRID CONNECTED SOLARENERGY

As of June 2017, India is the proud owner of two numbers of world's top five biggest solar power plants, namely Kurnool and Kamuthi Solar Plants. Old project of 1000 MW, located in Andhra Pradesh has third position worldwide and the ultimate project of 648 MW lying in Tamil Nadu positions fifth globally in their abilities as on 2017. Ministry of New and Renewable Energy (MNRE) announced that India's solar capacity has boosted up by 370% during the last three years.

A. Commissioning Condition of Indian Grid Connected Solar Projects

The entire additive capability of grid connected solar projects as on October 2017 from different states is 15604.76 MW. The initiation position of the Nation's Grid connected solar projects as on October 2017 is given in Table 1.

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 total installed capability of Power stations in the country as on 31st December 2017 is 330860.58 MW, from which 60157.66 MW is produced from Renewable Energy Sources (RES). The various factors of RES are rendered in Fig. 3. From the figure, it is graphic that around 25% of the overall renewable energy of the country is added by Solar.

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

The country shows noteworthy advancement in Renewable Energy sector. The advancement and additive acquirements of various grid interactional power outlines under Ministry of New and Renewable Energy (MNRE) as on 31st December 2017 is equipped in Table 2.

Figure 3 Installed capacities of RES in India as on 2017

Table 2 Progress and Cumulative Accomplishments 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 declared in a PV magazine that, as of November 2017, almost 48% portion of total installed capacity of Renewable energy is equipped by solar. India has set a milepost by the largest PV power capacity summation of 5525.98MW in 2017, of which 1.7GW is supplied by rooftop solar .

D. Tentative Solar Power Objective

Ministry of New and Renewable Energy has casted a provisional solar power objective of 99533 MW for year 2022. The dissolution of this objective, to be completed from all the partsis instanced in Fig. 4. It is open that, about 31%, 28%, 26% and 12% of the overall part are directed for Northern Part, Western Part, Southern Part and Eastern Part severally. On the other hand, the North Eastern Part & islands (Andaman & Nicobar island & Lakshadweep island) collectively reports to 1.24% of overall solar power objective.

E. Comparing of Renewable Power Generation during 2016 and 2017

Comparing of the overall power generation & renewable power generation of the country in 2016 and 2017 is done in Table 3. The origin wise power generation from the Renewable, for October month of 2016 & 2017 is represented in Fig. 5. It can be mentioned that the solar power generation is gained nearly by 1000 MU for October month of 2017, when comparisonto the same month of previous year. The multiplex advancement of installed capability from RES of the nation, right from the 6th plan is presented in Fig4.

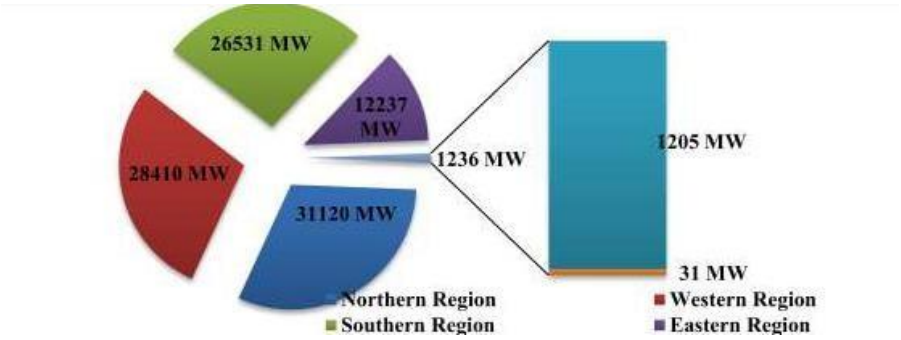

Figure 4 Provisional area wise separation of solar power objective for 2022

Table 3 Comparison of Nation's Power production 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

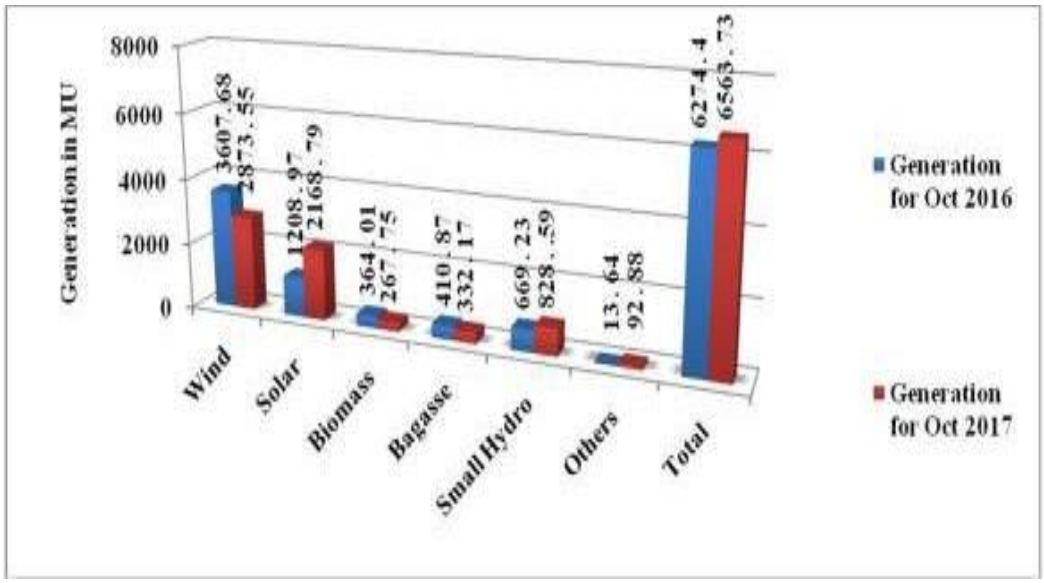

Figure 5 Origin wise power production from the renewables for the October 2016 & 2017

F. Year-Wise objectives of National Solar Mission

The year-wise objectives of National Solar Mission up to 2022, to achieve its hope of install 40 GW of Rooftop solar projects & 60 GW of big & medium scale projects, collectively contributing 100 GW, are given in Table 4.

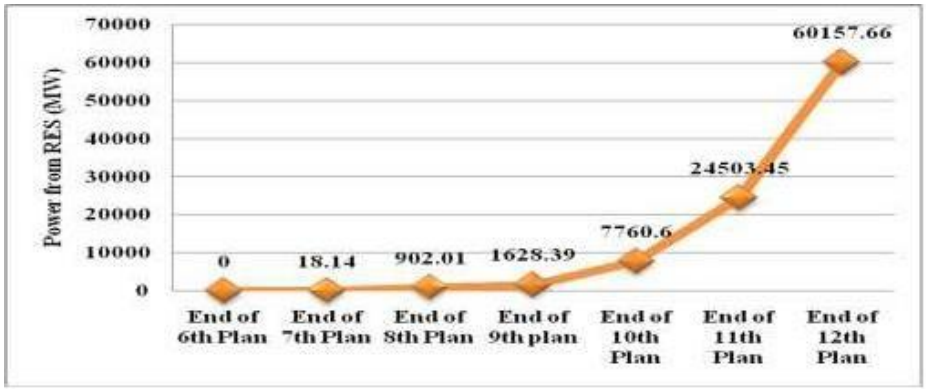

Figure 6 Advancement of Installed Capacity from RES

Table 4 Year wise objectives 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 extended solar power generators of the country with at least 10 MW capacity are given in Table 5. Bhadla solar plant of Rajasthan has incurred a minimal solar tariff of INR 2.044/unit.

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. EXECUTION FACTORS OF GRID CONNECTED SOLAR POWER PLANT

Grid connected Solar PV production enables the effective use of harnessed solar energy. However, the technological aspects of PV generator & utility side shall be satisfied at the same time, to raise the dependability of the grid. For the intent of enquiring the grid connected PV systems, the International Energy Agency (IEA) has set up some stipulation like performance ratio, capacity factor, energy output, array yield, reference yield, final yield, system efficiency, module efficiency, inverter efficiency, and energy loss which admits both system loss & capture loss. The disparate systems with variable size and vicinity can be correlate by using the renormalized execution arraign values. These performance evaluators are as follows:

A. Performance Ratio (PR)

It is one of the crucial indicants for evaluating the operation of PV systems. It is outlined asratio of final yield to reference yield. It represents the dependability & efficaciousness of thePV system. It suggests the nearness with which the PV system functions in real operationalconditions to that of ideal execution. Systems with disparate capabilities, climbing structures,and positions can be equated with this parameter. It is the amount of energy that can beinterjected to the grid after abatement of losses. It is verbalized in percentage. It is also known as "Quality Factor".

B. Capacity Utilization Factor (CUF)

It is in case found by divisional actual yearly energy turnout, by the measure of energy which the solar PV plant could produce, if it runs at full rated power for all the hours of a day in a year. This factor expresses the energy rendered by a PV plant.

C. Array Yield (Y_A)

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

D. Final Yield (Y_F)

It is conveying the AC energy generated by the PV power plant for a specific term (day, month or year) as a fraction of its rated DC power at Standard Testing Conditions (STC). It isalso known as "Yield factor".

E. Reference Yield (Y_R)

Distribution of overall in plane solar insolation H_t (kWh/m2) by the source irradiation G (1kW/m2) is known as Reference Yield. It conveys the number of maximum sun-hours in a day.

F. Array capture Loss (L_C)

It is found by deducting array yield from the reference yield. They are induced due to solarPV array losses.

G. System Loss (L_S)

The difference between array yield and final yield is known as System loss. They are induced as a result of noncontinuous performance of inverter.

H. System Efficiency(η_{sys})

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

I. Inverter Efficiency(η_{inv})

It is also called as conversion efficiency. It is the formulation of produced AC power of inverter as a fraction of produced DC power of the PV array system.

IV. LITERATURE REVIEW

Several projects for assessing the execution of Solar PV plant are casted by International Energy Agency (IEA). Due to non-affiliation of India with IEA, the functioning criteria of Indian Solar Photovoltaic power plants as per IEC Standard 61724 are not gettable. Hence itis necessity to document the execution of the same, to interpret their existent functioning conditions, and thereby proper steps should be taken to boost their performance. This has actuated the writers to do an aggressive literature analyzation on the execution of the Solar PV plants in India and it is discussed in Table 6.

2.1 Literature Reviewed

Joshi A S et al., (2009) has done a thorough review of photovoltaic and photovoltaic thermal systems had been done on the basis of its performance based on electrical as well as thermal output. Photovoltaic systems had been classified according to their use, i.e., electricity production and thermal applications along with the electricity production. The application of various photovoltaic systems also discussed in detail. The performance analysis including all aspects, e.g., electrical, thermal, energy, and exergy efficiency had been also discussed. Acase study for PV and PV/T system based on exergetic analysis has been presented.

Kumar et al., has used PVsyst and PV-GIS software's are used for simulation. Annual energy generated is 15798.192 MWh. Efficiency of panel is 14.06%. Its Capacity Utilization Factor (CUF) is 17.68%. Annual Performance Ratio is 86.12%. The variation of Final yield is in the range of 1.96 to 5.07h/d. 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. Efficiency of PV array is 13.3%. The actual energy generation is compared with simulated results of PV syst and solar GIS.

Sharma et al., has used PVsyst software for simulation. The annual average performance ratio, capacity factor and System efficiency are 74%,9.27% and 8.3% respectively. Referenceyield fluctuates between 2.29 h/d to 3.53 h/d. The variation of final yield is in the range of
1.45 to 2.84 h/d. The energy supplied by the plant is 154.43 MWh.

Dobaria et al., has generated 8265 KWh total energy per annum. Measured energy yield is 1636 kWh/kWp. Array yield varies from 3.1 h/d to 5.7 h/d. Final yield varies from 2.96 h/d to
5.43 h/d. Its Annual average final yield is 4.49 h/d. Reference yield varies from 4.22 h/d to
7.22 h/d. Performance ratio is in the range of 0.68 to 0.83 with an average value of 0.74. Annual average Array capture Loss, system loss and specific yield are 1.35 h/d, 0.23h/d and 4.49 h/d respectively.

Ramoliya et al., PVsyst 5.41 software is used for simulation. Out of 1449870 KWh of energy generated, 1416980 KWh of energy is injected to the grid. The average performance ratio is 0.764. 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. The average efficiency of the system is 11.02% and that of PV array is 14.60%. Normalized value of the array Yield and Final Yield are 0.01 kWh/kWp/day and 3.88 kWh/kWp/day respectively.

V. CONCLUSION

India renders an outrageous progressive advancement in the solar energy sphere. Presently, thecountry is one among the top ten nations in Solar Photovoltaic summations & overall accredited solar photovoltaic capabilities. Ministry of New and Renewable Energy informs that, around 15.60 GW capacities have been summated to Indian solar grid as on October2017. The country targets for 100GW of power to be harnessed by the sun by 2022. Thus, to attain this vast aim, an in-depth awareness of subsisting condition of Indian grid connected solar power systems is essential. This paper presents a copious revaluation of execution audit of grid connected Solar Photovoltaic plants in India. First of all, the present-day conditions in Indian grid connected solar power are discoursed. Various factors, admitting the initiation position of grid connected solar projects as of 2017, Induced capability of Renewable Energy Sources in India as of 2017 has been listed by the writer. Also, the advancement & development of Indian renewable energy power sector with an accent on solar energy power sector, approximation solar power objectives for different areas up to 2022, elaborated annual objectives of National Solar mission, & uncommon of the major Solar power plants of India are handled. After, the parameters regulating the evaluation of the solar power plants has been explained. Then the recent clauses on

performance review of grid connected solar power plants in India, released from the 2012 year onward have been reviewed and its abbreviationis represented in the paper.
Hence this follows up clause will emphatically help the researchers, engineers, &academicians to take suitable steps in amending the execution of Indian grid connected solar power systems, thereby the ambition of attaining 100 GW of solar power by 2022, may come into realness in future.

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