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# Solar Energy Assessment in Various Regions of Indian Sub-continent

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## Abstract

The demand for sustainable energy has increased significantly over the years due to the rapid depletion of fossil fuels. The solar photovoltaic system has been the advantage of converting solar irradiation directly to electricity, and it is suitable for most of the regions. But in the case of solar energy conversion, the voltage evolved from the solar photovoltaic cells is not adequate to meet the energy demand. Therefore, the converters and inverters with energy storage systems are used to fulfill the energy demand. These conversion architectures create new challenges for effective management of the grid. Due to the evaluation of power generation, load in a particular region or area, let us simplify with the help of the duck curve. The study is focused on the energy auditing, assessment, and measurement of solar irradiation from PV system design software. This graphical representation is implemented with a typical electricity load pattern at any region.

**Keywords:** solar-PV system, solar irradiation, modular scale battery energy storage system, multilevel converters, duck curves

## 1. Introduction

The global solar power demand capacity will grow by 9% every year between 2018 and 2050. According to that a new strategy has been released by the International Renewable Energy Agency (IRENA). The study of future Photovoltaic energy states the global solar capacity will be increase from 480 GW in 2018 to over 8000 Giga Watt by 2050 [1, 2]. The solar energy can be predicted to some degree from analysis level of climate conditions at the project site, but for the basic explanation that the atmosphere cannot be tracked. But, the solar panels can supply power on demand [3]. The evaluation of power generation load in a certain region shortens by using for duck curve [4, 5]. In the case of solar energy consumers often know in advance that their investments can produce energy only during the daytime. A solar system has a constant power output, the system only needs to be sized larger and it's needed for excess energy storage system [6–8]. There are 3 emerging storage technologies that is viable energy solution for renewables such as solar or wind in recent scenario such as 1. Smart batteries, 2. Heat based energy storage, 3. Hydrogen fuel-cells. This approach is not suitable in reality, because the energy loss during charge/discharging duty cycle is up to 10–15%, and the large scale energy storage is currently much expensive [9, 10]. This practical problem as renewable energy has become more widespread, and to get consent power output from a solar system.

To implement the intermittency challenges for effective Modular Scale Battery Energy Storage System (MSBESS), and it's established as a necessary component for solar integrated micro grid system [11–13]. India has set itself an admiral target of 175 GW of Renewable energy by 2022. The target will principally comprise of 40 GW Rooftop and 60 GW through large and medium scale grid connected solar power projects in India [14–16]. In a span of 3 hrs in the evening the conventional sources need to ramp up production by almost 10 GW. A framework was improved to the utilization of localized solar irradiation, and availability of Indian sub-continent region with associating with the open source archive database [17–22]. The results and analysis are presented for detailed study for various region of solar resource potential evaluation. The measurements and demonstration of a simplified with PV software system design latest version 7.0.2 under the simulation of regional solar energy requirements of real-time basis level. Accordingly, one of the main restriction of solar energy, there is no control over when the PV system will be producing the power. In this situation can be solved by converters to interconnection in between the load, and as well as PV storage management system.

2. Major solar irradiation level in India region

India has a high potential for solar power Generation on about 300 direct sunshine days per year. The regular solar incident in India varies with an annual sunlight of 4 to 7 kWh/m<sup>2</sup>, which is about 1500 to 2000 hours above the irradiation level gross energy consumption. The renewable energy generated by India in 2020 amounted to grown up 9.46%. **Table 1** shows the major irradiation level solar hot spot evaluated in India. Total solar power capacity was installed in India 35,739 MW. **Figure 1** show the annual average insolation solar hotspot map.

Monthly global average insolation data is collected the entire topography of India with in longitudes 67° to 97°E and 9° to 39°N. The various region of global insolation like as solar power generation identified hotspot in India based on surface measurements obtained from solar radiation station. The average global insolation map is employed to produce for using global information system [28, 29]. The insolation solar direct global is given by the Eq. (1),

State	Total area (1500 ha)	Total solar potential energy	High irradiation insolation level
Karnataka [2]	19,050	24.7 GW	3.5–4.0 kWh/m <sup>2</sup> /day
Rajasthan [17]	34,270	4.8 GW	5–7 kWh/m <sup>2</sup> /day
Maharashtra [17]	30,758	64.32 GW	3–4 kWh/m <sup>2</sup> /day
Himachal Pradesh [23]	4548	33.8 GW	3–4 kWh/m <sup>2</sup> /day
Jammu Kashmir [23]	3781	111.05 GW	3–4 kWh/m <sup>2</sup> /day
Andhra Pradesh [24]	27,505	38.4 GW	3–4.5 kWh/m <sup>2</sup> /day
Gujarat [24]	18,866	35.7 GW	4–4.7 kWh/m <sup>2</sup> /day
Odisha [25]	15,043	25.7 GW	4–4.7 kWh/m <sup>2</sup> /day
Madhya Pradesh [26]	30,756	61.6 GW	2.9–4.0 kWh/m <sup>2</sup> /day
Uttar Pradesh [26]	24,170	22.8 GW	2.9–3.9 kWh/m <sup>2</sup> /day
Haryana [27]	18,096	73.2 MW	3.5–4.5 kWh/m <sup>2</sup> /day

**Table 1.**  
Major solar irradiation hot spot.

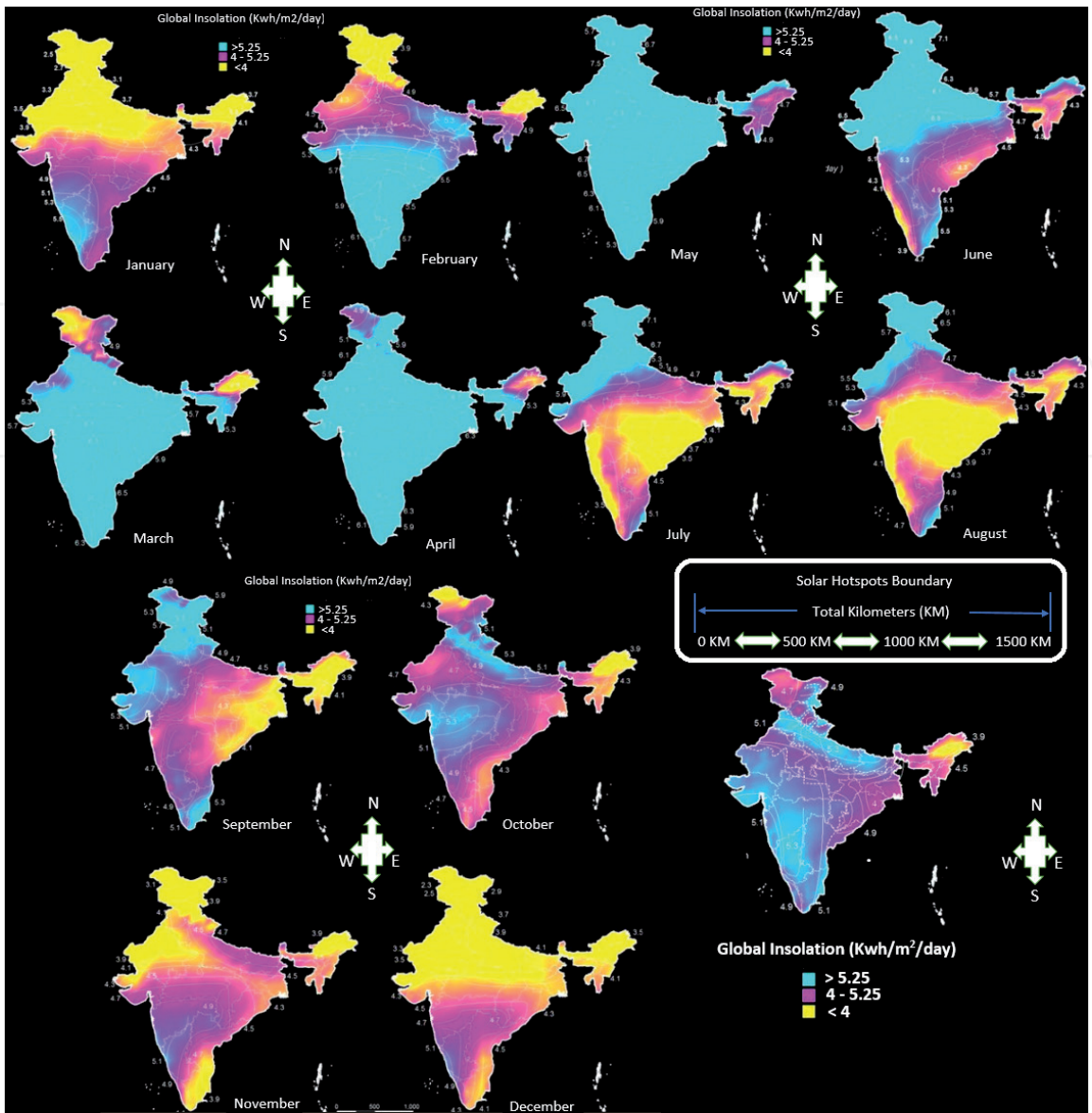


Figure 1.  
Annual average insolation solar hotspot map.

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$$I = (G - D) / \sin \phi \tag{1}$$

Where, G is solar direct global insolation, D is the diffuse component, and  $\Phi$  is the sun elevation angle. The installation by five regional solar power generation as given in **Table 2**. There are three main strategy of maximum power generated from solar in India: 1. ground mounted system, 2. rooftop, and 3. off-grid (stand-alone mode). The global radiation is the sum of the total horizontal radiation at any location calculated by radiation directly ( $I_d$ ) and radiation diffusely ( $I_b$ ) given in the Eq. (2). Most of the individual researchers have proposed numerous models for estimating the meteorological application of global radiation parameters include such as cloudiness, air temperature etc. The global radiation level is calculated by daily solar radiation level in horizontal surface [30, 31]. That is average of the hourly global radiation on the surface as given in Eq. (3). Firz et al. (2004) have suggested change of solar variation depends on the effect of sun earth distance and also the extraterrestrial global radiation on horizontal surface at a location is given by the Eq. (4).

Month	Indian Regional solar power generation (GW)					Total (GW)
	North	West	South	East	North-East	
Jan 2020	945.6	904.8	2712.8	48.3	1.04	4612.7
Feb 2020	1151.8	979.1	2906.1	51.9	1.5	5090.6
Mar 2020	1218.1	1091.0	3253.8	68.6	1.59	5633.3
Apr 2020	839.9	903.7	2358.8	64.6	1.41	4168.6
May 2020	942.8	926.4	2402.7	53.9	1.3	4327.4
June 2020	932.4	787.4	2136.1	61.1	1.02	3918.1
July 2020	785.6	702.8	1889.8	48.4	1.2	3428.0
Aug 2020	796.6	630.7	2111.3	36.0	0.97	3575.7
Sep 2020	885.5	585.1	2054.6	38.8	0.93	3565.1
Oct 2020	988.5	763.8	2074.8	54.2	0.9	3882.41
Nov 2020	807.4	776.9	2305.0	46.2	1.07	3936.8

**Table 2.**  
*Installation of five regional solar power generation.*

$$I_H = I_d + I_b \tag{2}$$

$$H_H = H_b + H_d \tag{3}$$

$$H_o = \frac{24 \times 3.6}{\prod} I_{sc} E_0 \left[ \left( \frac{\prod}{180} \right) w_s (\sin \delta \sin \varphi) + (\cos \delta \cos \varphi \sin w_s) \right] \tag{4}$$

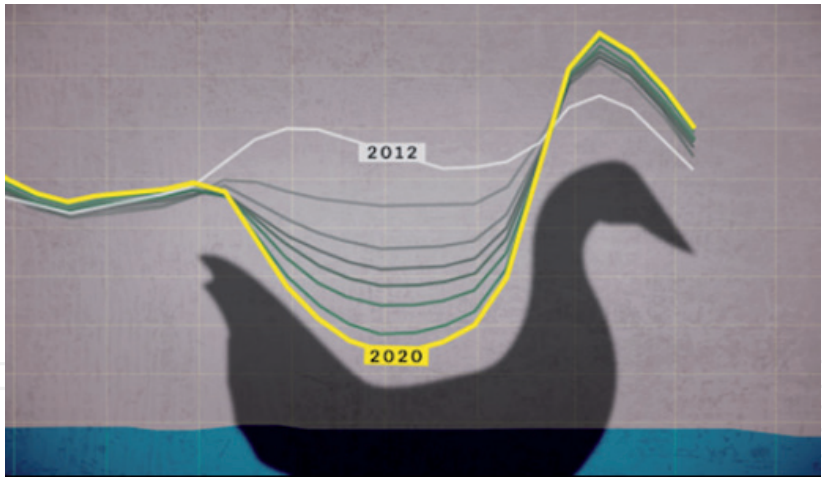
Where,  $H_0$  - daily extraterrestrial global radiation ( $KJm^{-2}.day^{-1}$ ),  $E_0$  - the eccentricity correction factor,  $W_s$  - Sunrise hour angle,  $\delta$  - Declination angle, and  $\varphi$  - latitude.

**3. Solar energy assessment in various region using duck curves**

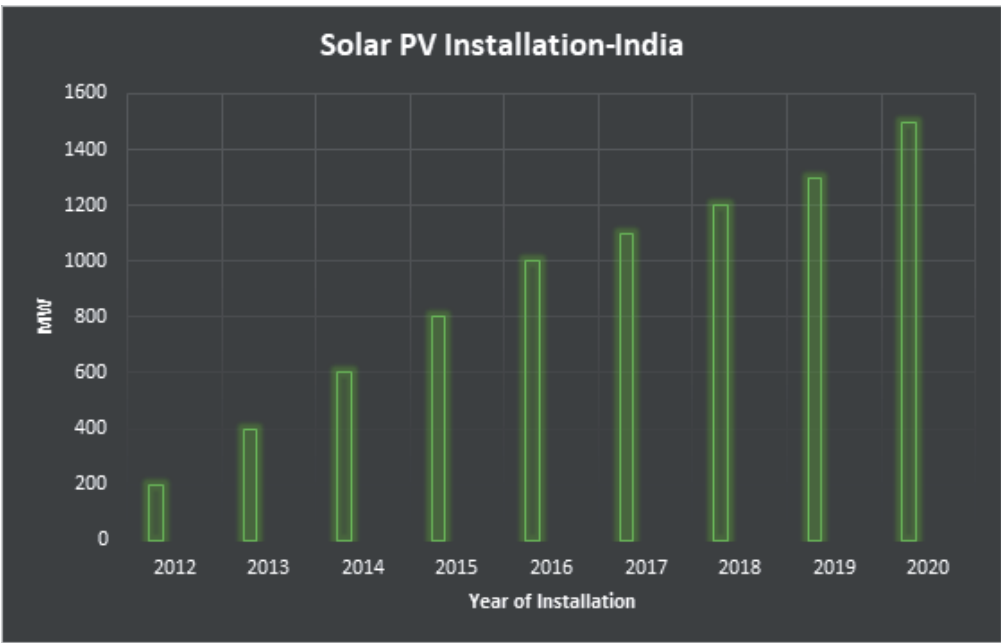
The duck curve is a graph of power production in electricity generation on a daily basis which shows a timeline disparity between peak demand and the production of renewable energy. As an example of solar production is increasing the net load curve is taking the shape of a duck’s belly. When the sun goes down, the energy demand from conventional power plants needs to quickly ramp up. **Figure 2** shows the evolution of duck curve from 2012 to 2020. In 2013, National Renewable Energy Laboratory (NREL) initially used the phrase of duck curve. NREL issued a graph containing the projected power load less, and its anticipated grid integrated solar power supply. The capacity of photovoltaic systems are highest generation of solar power during the day at 10 a.m. towards 5 p.m. it poses a danger that the grid will destabilize over generation [32]. Similarly, after 5 p.m., solar power generation falls quickly, leading to increases the electricity consumption from other sources which need to accelerate their production shortly. This raises the possibility that generation costs and blackouts will be increased if demand is not met.

The peak demand occurs after sunset in many energy markets when solar power is not available anymore. In areas where there has been a significant amount of solar





**Figure 2.**  
*Evolution of the duck curve.*



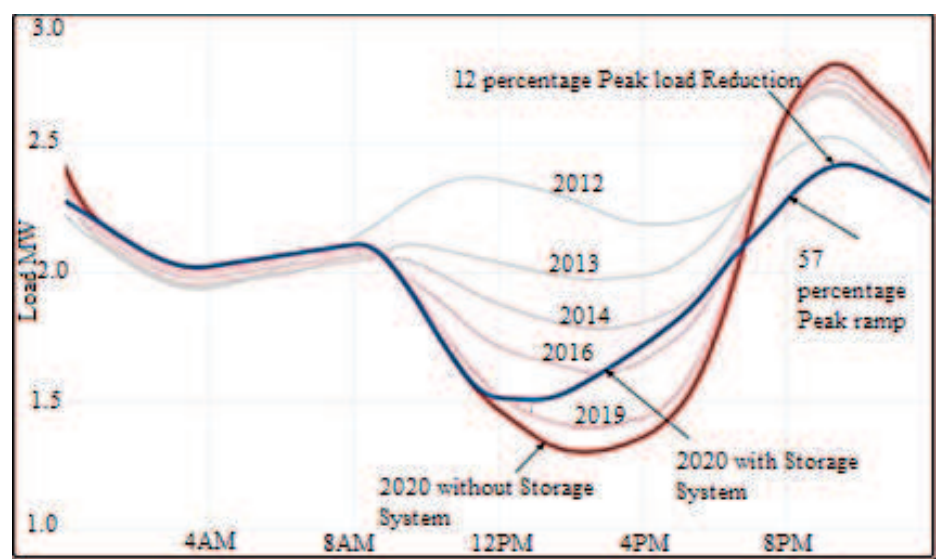
**Figure 3.**  
*PV installation in India.*

power, the amount of power to be generated from sources other than solar or wind shows that around the sunset and peaks in the middle of the night, a chart similar to the silhouette of a duck is created. Unless energy storage is available in some way, after high solar generation companies have to rapidly increase their power production around sunset to repay the loss of solar generation, which is a major concern for grid operators, where photovoltaic expand rapidly [33]. Fly wheeled batteries were found to provide excellent frequency control [34]. Short-term usage of batteries, large enough in use, can help flatten the curve of the duck and avoid fluctuation by generators, which can help maintain the voltage profile. The issue of a duck curve is mainly in India with because of high solar integration, while there is no integration of the grid in other major solar energy producing states such as China and United states [35]. **Figure 3** shows the PV plant installations in India from 2012 to 2020. The analysis has been taken from 2012 since the duck curve came into existence from the year 2012. This article explains the promising solution of the Duck curve as to implement the battery storage systems.

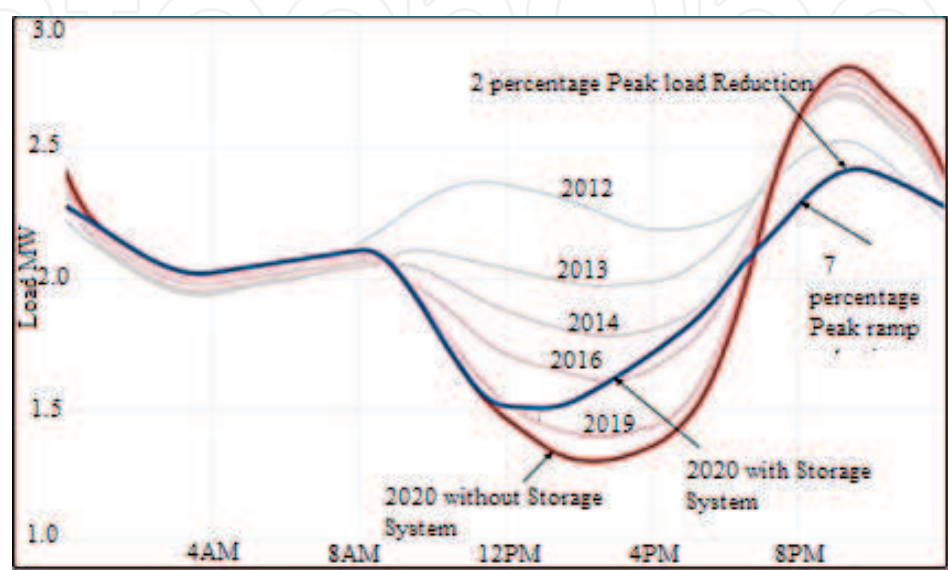
**Figure 4** shows the duck curve analysis of Rajasthan since it has a PV power plant installed in an area of 34,270 ha (hectare), and the net output evolved from the PV station is about 4.8 GW [36]. The highest irradiation insolation level is 5–7 kWh/m<sup>2</sup>/day.

Since that desert is located in Rajasthan (state of Indian sub-continent) the amount of solar radiation received in that geographical area is greater than other states but If we consider the duck curve in **Figure 4** shows that from 2012 to 2020 the ducks belly goes on increasing during the hours 4 am to 8 pm. A blue color line in **Figure 4** indicates that the best solution to overcome the duck curve is to implement storage system (SS). If we observe the graph with SS the ducks belly has decreased whereas if SS is not used then the Ducks belly is increased which is indicated by red color. The ramp reduction without SS is only about 12% whereas the ramp reduction with SS is about 57%.

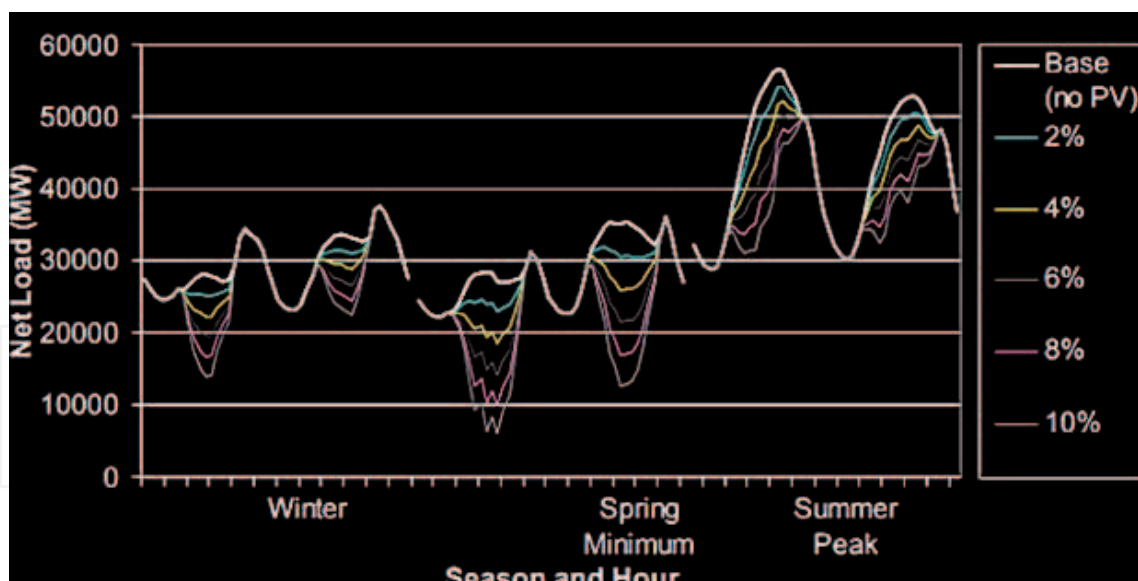
**Figure 5** shows the duck curve analysis of Haryana (state of Indian sub-continent) since it has a PV power plant installed in an area of 18,096 ha, and the net output evolved from the PV station is about 73.2 MW [37]. The highest irradiation insolation level is 3.5–4.5 kWh/m<sup>2</sup>/day. Since Haryana is located in the northern part of India and has a very cold climate the amount of solar radiation received in that geographical area is lesser than other states but If we consider the duck curve in **Figure 5** shows that from 2012 to 2020 the ducks belly goes on increasing during the hours 12 pm to 6 pm. A blue color line in **Figure 5** indicates that the best solution to overcome the duck curve is to implement storage system (SS). If we observe



**Figure 4.**  
*Graphical analysis of duck curve in Rajasthan.*



**Figure 5.**  
*Graphical analysis of duck curve in Haryana.*



**Figure 6.**  
*Graphical analysis of duck curve in Rajasthan during winter spring and summer.*

the graph with SS the ducks belly has decreased whereas if SS is not used then the Ducks belly is increased which is indicated by red color. The ramp reduction without SS is only about 2% whereas the ramp reduction with SS is about 7%.

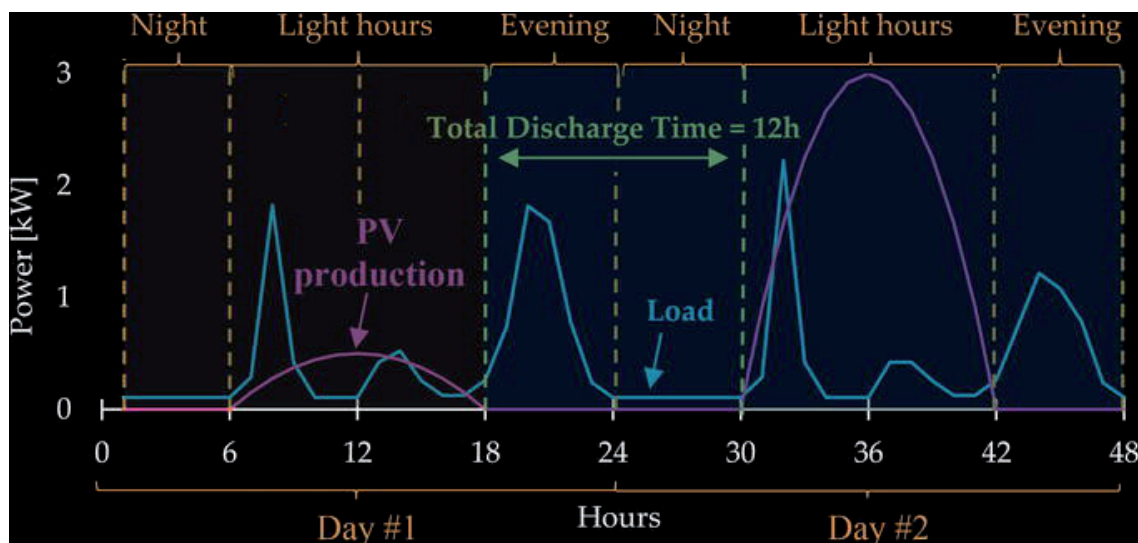
**Figure 6** shows the Duck curve analysis from 2014 to 2020 of the Rajasthan state with respect to the seasons. Three seasons taken into consideration such as the winter, spring and summer, the amount of solar radiation received in the geographical area of Rajasthan during winter is very less since less solar radiation. So the use of conventional energy sources like hydro or thermal power has demand. But later when seasons change the graph shows changes in the irradiation level and energy utilization.

#### 4. Modular scale-battery energy storage system

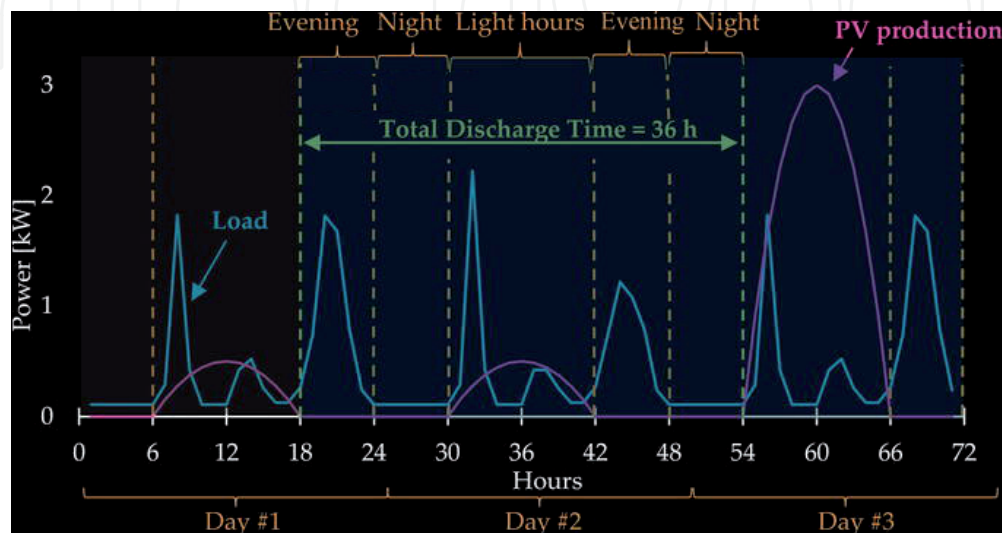
In India, the fast moving towards a renewable energy future with solar battery system. In order to continuous growing electricity demand with minimize the fossil fuel and environmental pollution. The maximum solar energy is wasted without energy storage devices i.e., battery or capacitor bank during in daytime [38], because in India sub-continental is the largest country in square 3,287,263 kilometers, and Solar-PV (S-PV) system can contribute in most of the production region in India. Due to extensive development of renewable resources are used to interconnect with micro-grid/ smart-grid approach [39]. Modular Scale -Battery Energy Storage System (MS-BESS) is enable power system operators, and it can interconnect utility provider with stored energy for lateral uses. The purpose of MS-BESS connected to a solar system could also work with protecting storage and reducing peak demand [40]. In existing solar batteries are manufactured with some limitations. It can be used for Li-Ion and Li-Po model batteries, that is incorporate the roles of cell balance, charging, discharge, cell display and defense. These tasks are done autonomously charging and discharging with 10–15% losses, the internal battery supplies the electricity for the analysis to be carried out, and extruded batteries with active batteries should be used. However, to charge normally MS-BMSS batteries must be attached in multilevel converters [41, 42]. The battery charging line is attached in parallel to solve this problem, while charging is achieved at low voltage using by parallel charging [43], and in India maximum rooftop [44], standalone models are fixed with residential, domestic purpose.



The battery storage system in India is proposed periodically power absorption to the grid during without peak load time. In this strategy selection is achieved 3 times per day to better match the consumption peak load of domestic user. Which occurs early in morning time slot 1: Starts at midnight and ends at 6.00 A.M, next time slot: 2 in between 6.00 A.M to 6.00 P.M, third time slot start at 6.00 P.M, and it can finish at mid-night. Finally satisfied by PV production is especially in winter time consumption level. In fact at 6.00 P.M the PV module system is absorbed weather forecasts for the next 24 hours, so the PV production period is almost getting over. The calculation of update storage battery management strategy and provisional energy balanced conditions are accurately find the quality of stored energy. In this time the battery do not charged and its supply transfer to the grid will not to be considered. The first model is shown in **Figure 7**. It can present the S-PV system and peak load for day one: in this first day the sky is clear at 6.00 P.M (Total discharging time is 12 hours). The battery storage and load will be mainly supplied with the help of PV module. The S-PV system in day two and three: the PV will minimum production, due to cloudy weather conditions. Thus, the MS-BMSS will maintain and manage the discharge of storage until in morning of the day, a total discharging time is 36 hours (discharging time in between 18 hours to 54 hours) as shown in **Figure 8**.



**Figure 7.**  
*PV module and load profile for two day (12 hours discharging time).*



**Figure 8.**  
*PV module and load profile for three days (36 hours discharging time).*

5. Measurements of solar grid system pre-sizing

The solar-grid connected system presizing in India as of July 2020. Predominantly, the measurement of irradiation level and system grid interaction in south India. S-PV system module type is standard, polycrystalline cells, and mounting method is tilt roof. Especially, the geographical site latitude are 11.41°N, longitude 76.70°E (Ooty), altitude 0 m, and time zone UT + 5.5. The PV field nominal standard test condition power is 30 kWp. The PV software system 7.0.2 Installation of solar collector plane

Month	Global horizontal plane kWh/m <sup>2</sup> /day	Global in tilted plane kWh/m <sup>2</sup> /day	System Output kWh/day	System Output kWh
Jan	6.15	7.46	188.3	5836
Feb	6.71	7.58	191.3	5357
Mar	6.56	6.85	173.2	5368
Apr	6.11	5.87	148.3	4450
May	5.89	5.10	129.2	4004
Jun	4.07	3.60	91.07	2732
July	4.01	3.58	90.45	2804
Aug	4.38	4.12	103.9	3221
Sep	4.24	4.28	107.8	3234
Oct	4.76	5.14	129.7	4021
Nov	4.75	5.57	140.4	4212
Dec	5.87	7.23	182.3	5651
Year	2.28	5.53	139.4	50,890

Table 3.  
System output graphical site in Ooty.

Month	Global horizontal plane kWh/m <sup>2</sup> /day	Global in tilted plane kWh/m <sup>2</sup> /day	System Output kWh/day	System Output kWh
Jan	4.82	5.55	139.8	4335
Feb	5.87	6.51	164.1	4594
Mar	6.33	6.62	166.9	5175
Apr	6.47	6.35	160.0	4800
May	6.21	5.82	146.7	4547
Jun	5.64	5.18	130.5	3914
July	5.20	4.82	121.6	3770
Aug	5.24	5.03	126.9	3933
Sep	5.35	5.44	137.1	4113
Oct	4.43	4.70	118.4	3671
Nov	3.84	4.25	107.2	3217
Dec	3.98	4.56	115.0	3565
Year	5.28	5.39	136.0	49,634

Table 4.  
System output graphical site in Chennai.

orientation tilt 15°, Azimuth 0°, and It will be produced maximum system output 139.4 kWh/day as shown in **Table 3**. In this zone solar sun radiation is very low due to wet season is overcast, and the dry season is cloudy weather zone. The temperature typically varies from 46°F to 74°F, and it is rarely below 40°F or above 80°F.

Another, geographical site latitude are 13.09°N, longitude 80.28°E (Chennai), time zone UT + 5.5, and altitude 0 m. The PV module and system installation should be the same characteristics pre-sizing evaluation, and it will be produced maximum system output 136.0 kWh/day as shown in **Table 4**. But, in this zone sun radiation is high. This report delivered the solar output does not depend on the sun temperature. Solar panel is increases heat with the effect of sun temperature, automatically the output current increases. However, the output voltage is linearly decreases. It's directly by changing the rate of solar heat delivered from atmosphere, and earth.

Year	Total capacity (MW)	Installation per year (MW)
2010	161	—
2011	461	300
2012	1205	744
2013	2319	1114
2014	2632	313
2015	3744	1112
2016	6763	3019
2017	12,289	5526
2018	21,651	9362
2019	28,181	6530
2020	34627	6446

Table 5.  
Statistical information on PV installations in India from 2010-2020.

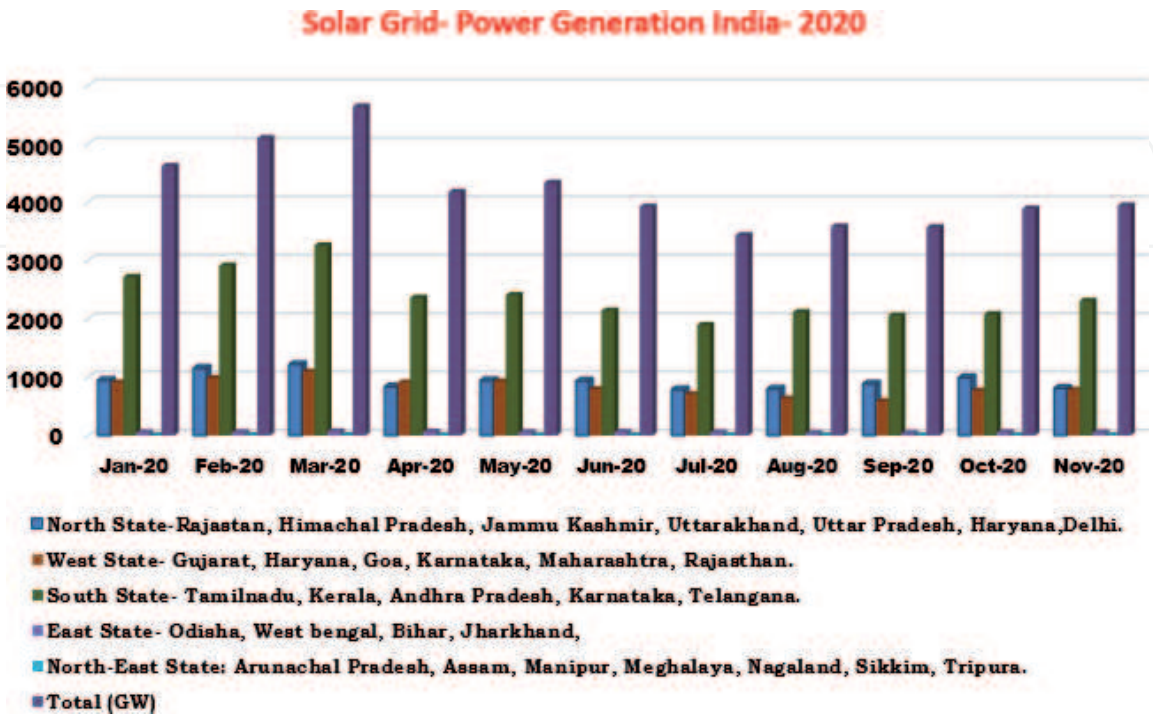


Figure 9.  
Solar grid connected generation in India 2020.

It can achieve indirectly by changing the cloud forming process. The maximum annual energy is 49.6 MW using for back ventilation property with free air circulation. **Table 5** shows the total PV installation as per year wise in India. The maximum energy is consumed by solar power grid connected module, and PV irradiations level are measurement in maximum production ranges in Rajasthan (North-state), Karnataka (South-state), and Telangana (South-state). **Figure 9** shows the solar power installed generation in Indian sub continental with different state.

## 6. Conclusion

The results has reveal that maximum region in Indian sub-continental an enormous solar power potential located in an different region, where solar radiations are regularly available in all overt the year (expect rainy or cloud season). Furthermore, PV energy is easy –maintain, cost saving, and high durable. So, in this type of PV energy is more suitable for Indian region with identified maximum solar irradiation under state-wise, assessment of PV power spectrum analysis, PV grid system pre-sizing, and battery management system. Finally, the statistical summary that solar insolation values ranges of 2.9–4.0 kWh/m<sup>2</sup>/day to 5–7 kWh/m<sup>2</sup>/day with an average value of 5.9 kWh/m<sup>2</sup>. The important role have been recommended for solar power in order to fulfill the country energy demand. Its way to a future need of sustainable development play major role in Indian sub-continental.

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