Most Probable Operating Conditions and Performance Assessment of Four PV Technologies at 10 Locations in India

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Abstract

The revised target of 100 GW of solar energy by 2022, under National Solar Mission has opened up new challenges in resource assessment, grid balancing, geographical distribution of these solar power plants and power forecasting for solar grid integration in India. The performance of fixed photovoltaic (PV) modules is site specific and largely depends on the climatic parameters, such as, solar radiation, temperature and other meteorological conditions. The present study is aimed to have a comparison of prevalent conditions, in terms of distribution of solar radiation and ambient temperature based on actual ground measurement data at 10 locations representing the different climatic zones in India. Consequently, in this study performance of four commercially available PV technologies are also assessed and compared with respect to annual energy generation and levelized cost of energy (LCOE) in the selected 10 locations. The study will be helpful to project developers and policy planners for better deployment of solar energy in India and to promote solar energy in total energy mix in India.

Keywords: Photovoltaics, Insolation, Irradiance, Annual energy generation, Temperature

1. Introduction

Photovoltaics constitute a major chunk of the India's proposed target of 100 GW of solar energy by 2022. Considerable amount of research work has already been carried out to know the behavior of different PV technologies in various climatic conditions. The study of site specific performance of various commercially available PV technologies is gaining importance as large scale deployments of PV power plants have become a reality because of lower cost of energy generation (Rawat et al., 2016). A novel climate classification criteria based on performance of four PV technologies was proposed along with technology selection criteria for a particular location (Dash et al., 2017). Solar radiation and temperature are two important climatic parameters that significantly affect the output of PV module. When the temperature increases, the electrical efficiency of the photovoltaic modules reduces irrespective of PV module technology. However, the extent of decrease is dependent on PV technology. The output current is directly proportional to the incident irradiance on the plane of the module and hence the power output. Some literature related to the effect of climate on PV modules performance is discussed below.

Most of the solar installations are located in the western regions of India due to the availability of higher solar radiation resources (Carr and Pryor, 2004; Guenounou et al., 2016; Tossa et al., 2016; Ferrada et al., 2015; Rawat et al., 2016; Makrides et al., 2014 and Huld et al. (2010). The electrical energy generation from on-grid PV solar systems of 1 kW capacity in the republic of Srpska, climate conditions and energy potential of the renewable sources has been studied by Pavlovic et al (2013). The performance of 1 kW solar plants of different types of PV technology such as mono-crystalline silicon, CdTe and CIS solar modules at 13 cities in the republic of Srpska has been evaluated by using PVGIS and the annual energy generation is compared. Characteristics of a 6150 Wp roof mounted grid-connected photovoltaic system at Mexico City studied by Santana-Rodŕiguez et al (2013). The study results compare the performance of four PV technologies such as mono-crystalline silicon, polycrystalline silicon, amorphous silicon and CdS/CdTe under the climatic conditions

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of Mexico City. The study concluded that, amorphous silicon PV technology performs better under temperature variations typical of Mexico City's environmental conditions. Swift (2013) compared the cost and financial returns for solar photovoltaic systems installed in different locations across the United States and results have demonstrated that, costs and financial returns of solar PV systems vary much depending on the location, where they are installed. This study confirmed that, detailed, site specific information about incentives, grid produced electricity rates, and levels of solar insolation is needed to determine whether the installation of a solar PV system makes economic sense in a particular location. Variation of PV efficiency on irradiance level for nine different commercially available PV module technologies are studied by Reindl et al. (2012). They have also analysed the irradiance distribution in tropical Singapore. Outdoor module testing data in Singapore for an entire year showed that, two energy peaks are observed at irradiance levels of one at around 400W/m^2 and 850W/m^2. The advantage of the peak performance at 850W/m^2 irradiance level not fully convertible to power as high light intensities in Singapore are always associated with higher module temperatures, which decreases the module efficiencies. Cucchiella and Dadamo (2012) estimated the energetic and environmental impacts of roof-mounted building-integrated photovoltaic systems located in Italy. The module efficiency, the embodied energy and the annual solar irradiance are variables that played a strong role in their analysis. Huld et al. (2008 and 2010) geographically assessed the performance of crystalline silicon photovoltaic (PV) modules over Europe. They developed a method that is based on a material specific analytical expression of the PV conversion efficiency, relative to nominal efficiency, as a function of module temperature and irradiance. Lim et al (2013) showed that, the power output of PV module decreases 0.469 %/°C with respect to temperature keeping all other parameters controlled. Actual Operating temperature is very important for photovoltaic energy conversion as observed by Skoplaki and Palyvos (2009) as the electrical efficiency and power output of a PV device varies linearly with operating temperature. The present study aims comparison of solar radiation and temperature based on actual ground measurement data at 10 geographically distributed locations in India, representing the different climatic zones. Consequently the performance of four different commercially available PV technologies also assessed and compared with respect to annual energy generation and leveized cost of energy generation (LCOE) in the selected 10 locations.

2. Methodology

National Institute of Wind Energy (NIWE), Chennai has set up the world’s largest network of Solar Radiation Resource Assessment (SRRA) stations across the country to develop investor grade, ground measured solar radiation data crucial for planning and implementation of solar power projects. The data has been obtained for the period of five years (2012-2016) for selected locations except Neemuch and Tura for which the data was available only for three years (2012-2014). One hour averaged data for Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), ambient temperature, wind speed, relative humidity and precipitation for the aforesaid ten locations was analyzed. The available hourly average data is first filtered for day time radiation and temperature. Solar Radiation and temperature data is segregated in three separate bins having irradiance distribution < 400 W/m^2, 400-800 W/m^2 and > 800 W/m^2 and < 20°C, 20-30°C and >30°C respectively in order to assess the favorable conditions. Further, performance of four commercially available PV technologies, namely Heterogeneous intrinsic thin film (HIT), Multi crystalline silicon (mC-Si), amorphous silicon (a-Si) and Cadmium Telluride (CdTe) are assessed at these 10 locations. Based on the environmental data, the annual energy generations for aforesaid four PV technologies have been estimated and levelised cost of energy (LCOE) calculated in order to have the techno-economic comparison of four PV technologies for the ten locations. Details of the locations selected for this study are exhibited in table-1 and figure-1. The locations are selected based on preliminary data assessment from the solar map, to cover maximum locations in the sunny and various climatic zones of India.

Tab.1: Details of the Locations Selected for the Study

Sr.No	Location	Latitude [ºN]	Longitude[ºE]	Altitude[m]
1	Bilaspur	22.08	82.18	267
2	Leh	34.14	77.48	3252
3	Chitradurga	14.22	76.43	760
4	Gandhinagar	23.15	72.67	65

5	Jodhpur	26.27	73.03	233
6	Karaikudi	10.09	78.80	101
7	Neemuch	24.48	74.87	501
8	Rajhmundry	17.06	81.87	93
9	Shegaon	20.78	76.68	288
10	Tura	25.53	90.21	397

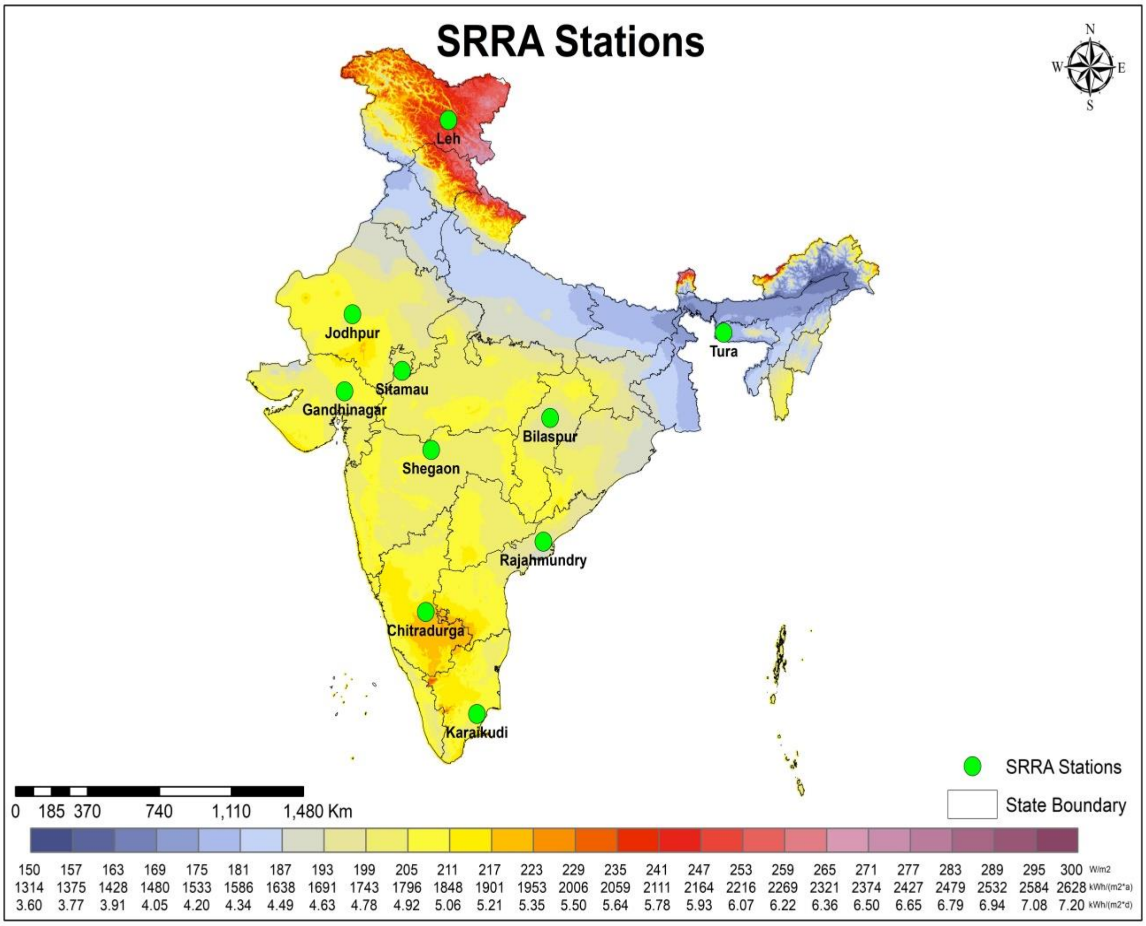

Fig. 1: Locations Selected for the Study

The annual energy generation has been computed using equations 1 and 2 given below.

$$M_T = A_T + (NOCT - 20) * \frac{GHI}{800} \qquad \text{[eq. 1]}$$

$$AEG = \sum(GHI * \eta - GHI * \eta * TC * (M_T - A_T)) \qquad \text{[eq. 2]}$$

where, AEG is the annual energy generation, M_T is the Module Temperature, A_T is the Ambient temperature, GHI is the Global Horizontal Irradiance, NOCT is the Nominal Operating Cell Temperature and η is the efficiency of the PV technology. The value of NOCT and TC which has been measured and used in the equation is given in Table-2 below;

Tab.2: Measured TC and NOCT of the Selected PV Modules

Type of Modules	**HIT**	**Multi C-Si**	**a-Si**	**CdTe**
TC (%/°C)	0.36	0.42	0.27	0.21
NOCT (°C)	44	41	49.2	45

The assumptions made towards calculation of levelised cost of energy from different technology PV power plant of 1 MW are given in table-3. The capital cost of the solar PV modules of different technology is assumed based on the latest price available in the business to business e-commerce website Alibaba.com. Other costs are assumed to be same for all the locations selected for the study. This assumption was based on the fact that, the supply chain and logistics cost will come down and remain same in all the locations when large scale deployment of solar PV power plants will take place throughout the country.

Tab. 3: Assumptions for Calculation of LCOE

Parameter/Technology	HIT	mC-Si	a-Si	CdTe
Capital Cost /MW	Rs.700 lakh	Rs. 330 Lakh	Rs. 350 lakh	Rs. 400 Lakh
Debt: Equity	70:30	70:30	70:30	70:30
Interest on debt	8.00 %	8.00 %	8.00 %	8.00 %
Return on equity	14.00%	14.00%	14.00%	14.00%
O & M cost	Rs. 7.00 lakh /MW with 5.72 % escalation every year			
Degradation rate	.50 %/yr	.50 %/yr	1.00%/yr	1.02%/yr
Discount Rate (d)	7.86 %	7.86 %	7.86 %	7.86 %
Depreciation	5.83 % for first 12 yrs then 1.54 % up to 25th year			

The method of calculation used for determining the generation potential and unit cost of energy from four PV technologies in the ten selected locations is given as under.

$$UCE = \frac{AC}{AEG} \quad \text{[eq. 3]}$$

$$AC = I_d + D + R + OM + I_{wc} \quad \text{[eq. 4]}$$

Where, UCE is the Unit Cost of Energy in Rs./kWh, AC is the Annualized Cost, I_d is the Interest on debt, D is the Depreciation, R is the Return on equity, OM is the operation and maintenance cost and I_{wc} is the Interest on working capital.

The Working Capital requirement in respect of solar PV Power projects is computed in accordance with the following procedure laid down by Central Electricity Regulatory Commission (CERC) with (a) Operation & Maintenance expenses for one month (b) Receivables equivalent to two months of energy charges for sale of electricity and (c) Maintenance spare at the rate of 15% of operation and maintenance expenses. Similarly, the discount rate has been computed to the post tax weighted average cost of capital on the basis of normative debt: equity ratio of 70:30 as proposed in the CERC Regulations (2017). Interest Rate considered for the loan component of 70 % of capital cost is 8.00 %. For equity component of 30 %, rate of Return on Equity (ROE) is considered at post tax rate of 14 %. The discount factor derived by this method for all technologies is given as under (Income tax rate is considered at 34.61% with 30% IT rate + 12% surcharge +3% Education cess):

$$d = \left(0.7 * I_d\left(1 - \frac{34.61}{100}\right)\right) + 0.3 * R \quad \text{[eq. 5]}$$

$$df = (1 + d)^n \quad \text{[eq. 6]}$$

$$LCOE = \frac{\sum UCE/df}{CRF} \quad \text{[eq. 7]}$$

$$CRF = \frac{d(1+d)^n}{(1+d)^{n-1}} \quad \text{[eq. 8]}$$

Where, ‘df’ is the discounted factor, n is the number of year, and CRF is the Capital Recovery Factor.

3. Results and Discussion

The characteristics of solar radiation and annual temperature distribution for the 10 selected locations are analysed and discussed as under:

3.1. Annual Irradiance Distribution at Various Temperatures at Bilaspur

The place Bilaspur, Chhattisgarh receives nearly 1521 kWh/m^2 of annual solar irradiance out of which major portion is received in the lower and medium irradiance range. 58.6% of the solar insolation is received in the irradiance level of less than 600 W/m^2 and nearly 93% of energy in the irradiance level of less than 800 W/m^2. Similarly, nearly 68 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The most frequent operating condition lies in temperature range 25-30^{o}C and irradiance range of up to 200 W/m^2. The annual irradiance distribution at various temperature ranges is given in figure-2.

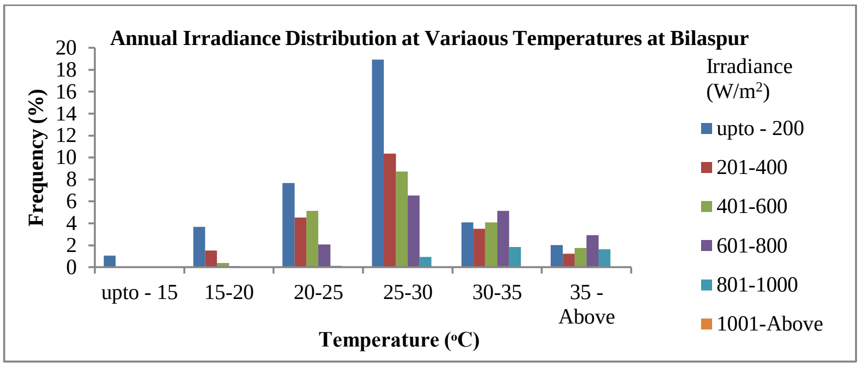

Fig. 2: Annual Irradiance Distributions at Bilaspur, Chhattisgarh

3.2. Annual Irradiance Distribution at Various Temperatures at Leh

Leh, located in the Indian State of Jammu and Kashmir, receives total annual solar irradiance of 1730 kWh/m^2. 47% of the solar insolation is received in the irradiance level of less than 600 W/m^2 and nearly 73% of energy in the irradiance level of less than 800 W/m^2. Similarly, nearly 94 % of the annual day time temperature is in the range of 25^{o}C and below. The annual irradiance distribution at various temperatures is shown in figure-3. The most frequent condition is in the temperature of below 15^{o}C and irradiance up to 200W/m^2.

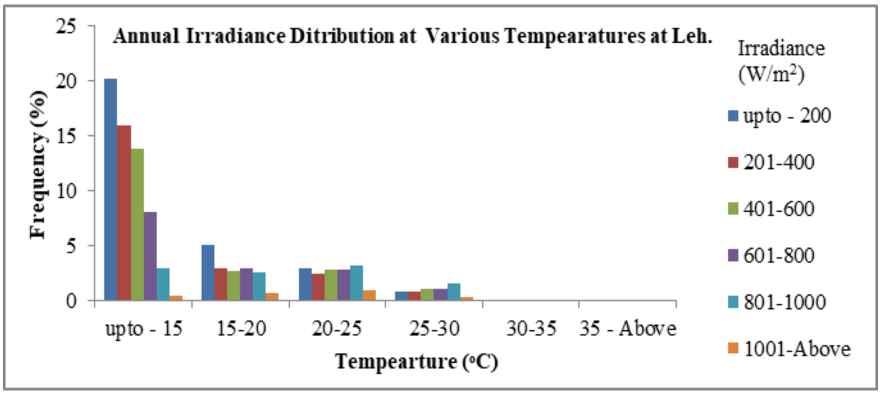

Fig. 3: Annual Irradiance Distributions at Leh, Jammu and Kashmir

3.3. Annual Irradiance Distribution at Various Temperatures at Chitradurga

Chitradurga in the Indian State of Karnataka, receives a total annual insolation of 1757 kWh/m^2 out of which substantial amount of its annual solar radiation in the medium and high irradiance ranges. 56 % of the solar insolation is received in the irradiance level of more than 600 W/m^2 and nearly 33 % of energy in the irradiance level of more than 800 W/m^2. Similarly, nearly 58 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The annual irradiance distribution at various temperatures is shown in figure-4. The most frequent operating condition lies in temperature range between 20^{o}C to 25^{o}C and up to 200 W/m^2.

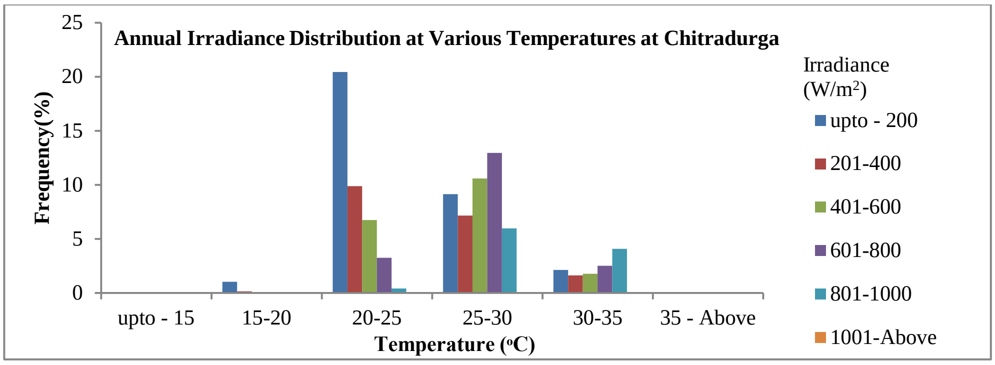

Fig. 4: Annual Irradiance Distributions at Chitradurga, Karnataka

3.4. Annual Irradiance Distribution at Various Temperatures at Gandhinagar

Gandhinagar located in the Indian State of Gujarat, receives total annual insolation of 1715 kWh/m^2 out of which substantial amount of its annual solar radiation in the medium and high irradiance ranges. Nearly 50 % of the solar insolation is received in the irradiance level of more than 600 W/m^2 and nearly 15 % of energy in the irradiance level of more than 800 W/m^2. Similarly, nearly 69 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The most frequent condition is in the temperature range of 25^{o}C to 30^{o}C. The annual irradiance distribution at various temperatures is shown in figure-5.

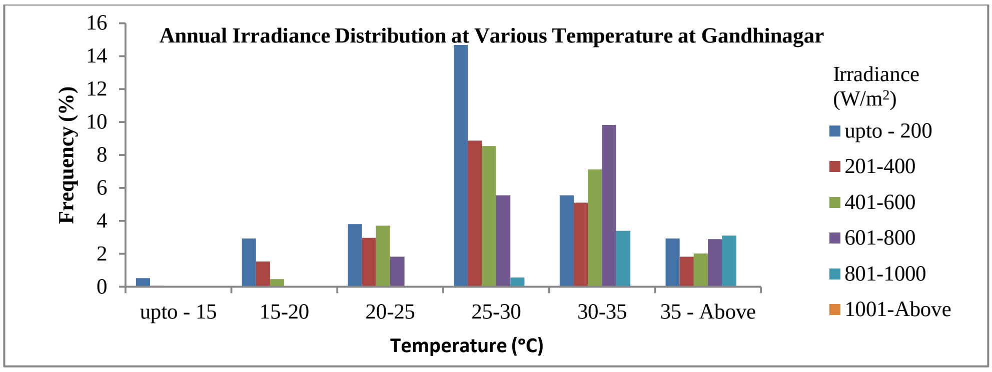

Fig. 5: Annual Irradiance Distributions at Gandhinagar, Gujarat

3.5. Annual Irradiance Distribution at Various Temperatures at Jodhpur

Jodhpur located in the Indian state of Rajasthan, receives total annual global horizontal irradiance of 1712 kWh/m^2 out of which substantial amount of its annual solar radiation in the medium and high irradiance ranges. Nearly 50 % of the solar insolation is received in the irradiance level of more than 600 W/m^2 and nearly 20 % of energy in the Irradiance level of more than 800 W/m^2. Similarly, nearly 60 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The most frequent condition lies within the temperature range of 30^{o}C to 35^{o}C and irradiance range of 600 W/m^2 to 800 W/m^2. The annual irradiance distributions at various temperatures are shown in figure-6.

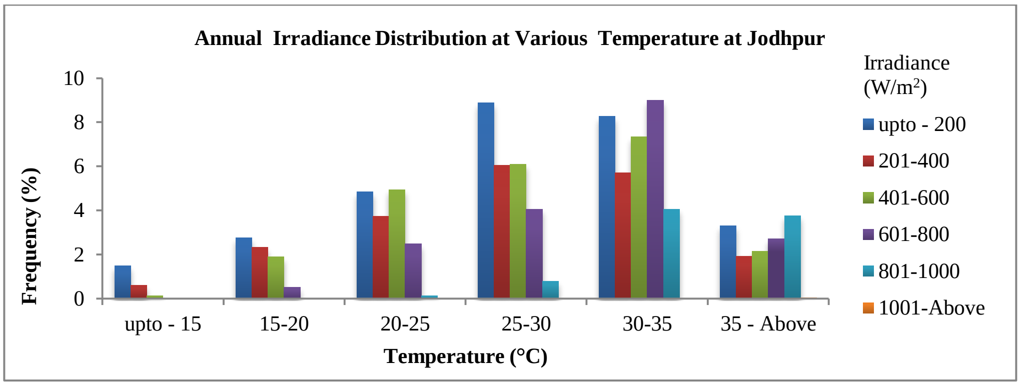

Fig. 6: Annual Irradiance Distribution at Jodhpur, Rajasthan

3.6. Annual Irradiance distribution at Various Temperatures at Karaikudi

Karaikudi is located in the Indian state of Tamil Nadu receives total annual horizontal irradiance of 1744 kWh/m^2 out of which substantial amount of its annual solar radiation in the medium and high irradiance ranges. Nearly 55 % of the solar insolation is received in the irradiance level of more than 600 W/m^2 and nearly 22 % of energy in the irradiance level of more than 800 W/m^2. Similarly, nearly 91% of the annual day time temperature is in the range of 25°C to 35°C. The annual irradiance distribution at various temperatures is shown in figure-7. The most frequent condition lies within the temperature range of 25°C to 30°C and irradiance up to 200 W/m^2.

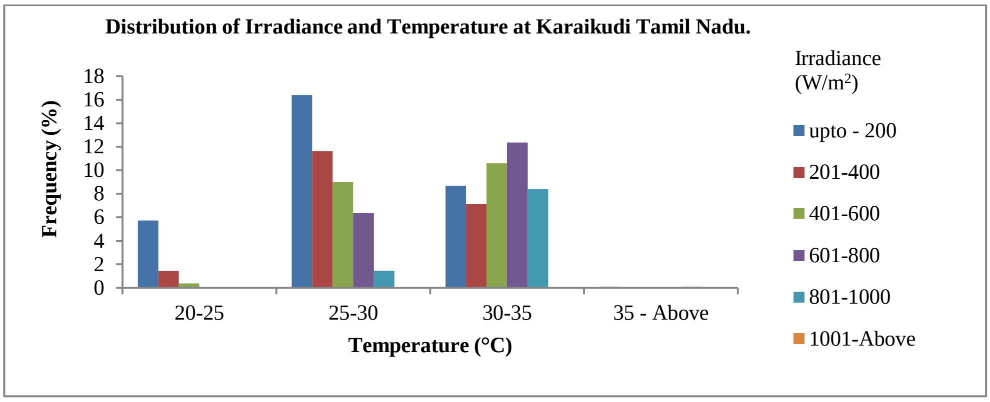

Fig.7: Annual Irradiance Distribution at Karaikudi, Tamil Nadu

3.7. Annual Irradiance Distribution at Various Temperatures at Neemuch

Neemuch located in the Indian state of Rajasthan, receives total annual global horizontal irradiance of 1635 kWh/m^2 out of which substantial amount of its annual solar radiation in the low and medium irradiance ranges. Nearly 53 % of the solar insolation is received in the irradiance level of less than 600 W/m^2 and nearly 87.8 % of energy in the irradiance level of less than 800 W/m^2. Similarly, nearly 58 % of the annual day time temperature is in the range of 25°C to 35°C. The annual irradiance distribution at various temperatures is shown in figure-8. The most frequent condition lies within the temperature range of 25°C to 30°C and irradiance level up to 200 W/m^2.

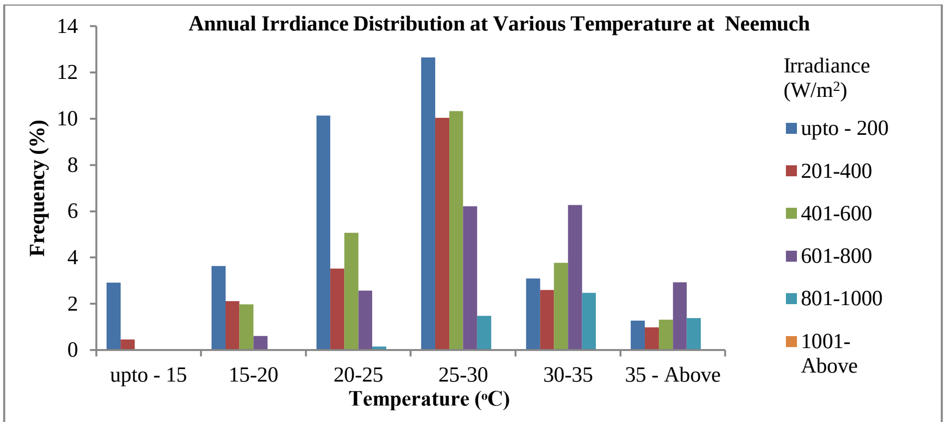

Fig. 8: Annual Irradiance Distribution at Neemuch, Madhya Pradesh

3.8. Annual Irradiance Distribution at Various Temperatures at Rajahmundry

Rajahmundry located in the Indian State of Andhra Pradesh, receives total annual global horizontal irradiance of 1595 kWh/m^2 out of which substantial amount of its annual solar radiation in the low and medium irradiance ranges. More than 50 % of the solar insolation is received in the irradiance level of less than 600 W/m^2 and nearly 84 % of energy in the irradiance level of less than 800 W/m^2. Similarly, nearly 75 % of the annual day time temperature is in the range of 25°C to 35°C. The annual irradiance distribution at various temperatures is shown in figure-9. The most frequent condition lies within the temperature range of 25°C to 30°C and irradiance range of up to 200 W/m^2 level.

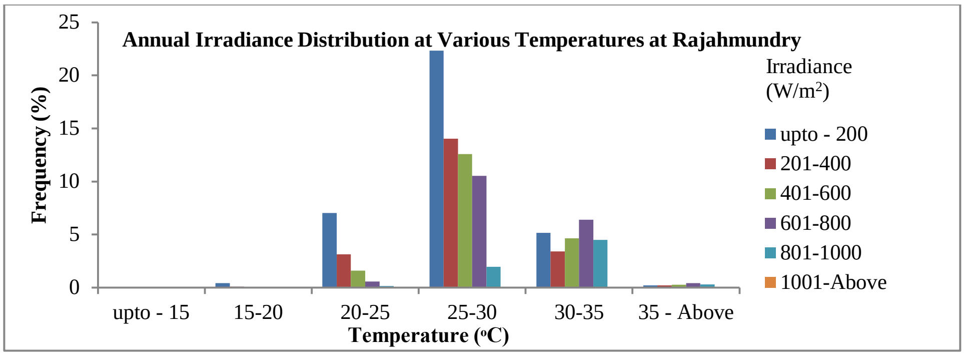

Fig. 9: Annual Irradiance Distributions at Rajahmundry, Andhra Pradesh

3.9. Annual Irradiance Distribution at Various Temperatures at Shegaon

Shegaon located in the Indian state of Maharashtra, receives total annual global horizontal irradiance of 1690 kWh/m^2 out of which substantial amount of its annual solar radiation in the medium and high irradiance ranges. More than 53 % of the solar insolation is received in the irradiance level of more than 600 W/m^2 and nearly 20 % of energy in the irradiance level of more than 800 W/m^2. Similarly, nearly 77 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The annual irradiance distribution at various temperatures is shown in figure-10. The most frequent condition lies within temperature range of 25^{o}C to 30^{o}C and irradiance level up to 200 W/m^2.

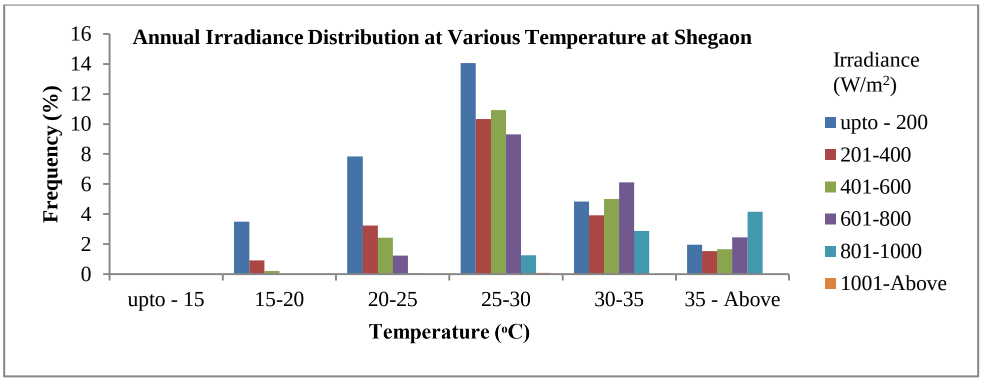

Fig. 10: Annual Irradiance Distributions at Shegaon, Maharashtra

3.10. Annual Irradiance Distribution at Various Temperatures at Tura

Tura located in the Indian state of Meghalaya situating in north east part, receives total global horizontal irradiance of 1472 Kwh/m^2 out of which substantial amount is in the low and medium irradiance ranges. More than 65 % of the solar insolation is received in the irradiance level of less than 600 W/m^2 and nearly 90 % of energy in the irradiance level of less than 800 W/m^2. Similarly, nearly 62 % of the annual day time temperature is in the range of 25^{o}C to 35^{o}C. The annual irradiance distribution at various temperatures is shown in figure-11. The most frequent condition lies in the temperature range of 25°C to 30°C and irradiance range up to 200 W/m^2.

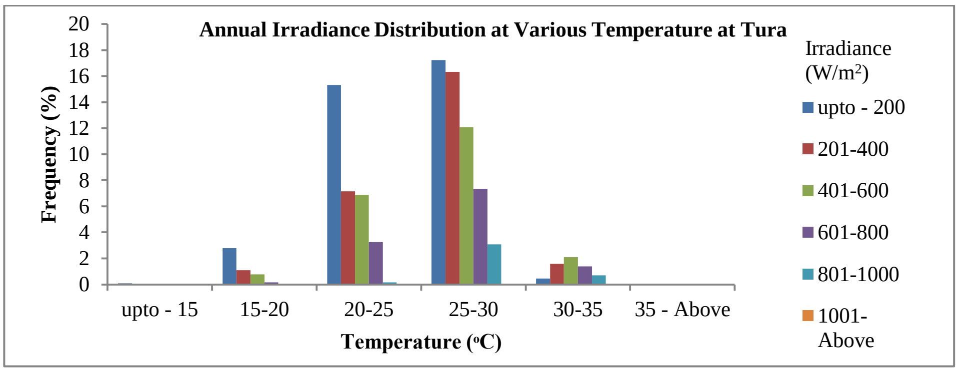

Fig.11: Annual Irradiance Distributions at Tura, Meghalaya

3.11. Comparison of Annual Irradiance Distribution and Annual Temperature Distribution for the Selected Locations

Based on the analysis of the actual ground measured data of selected 10 locations, it has been observed that, the maximum annual sunlight hour (total duration having GHI more than 50 W/m^2 in a year) is received at Chitradurga followed by Tura and Bilaspur. Similarly, the locations receiving maximum radiation at low irradiance level (<400 W/m2) is Tura followed by Bilaspur and Rajahmundry The irradiance distribution is given at figure-12 and the temperature distribution is given at figure-13.

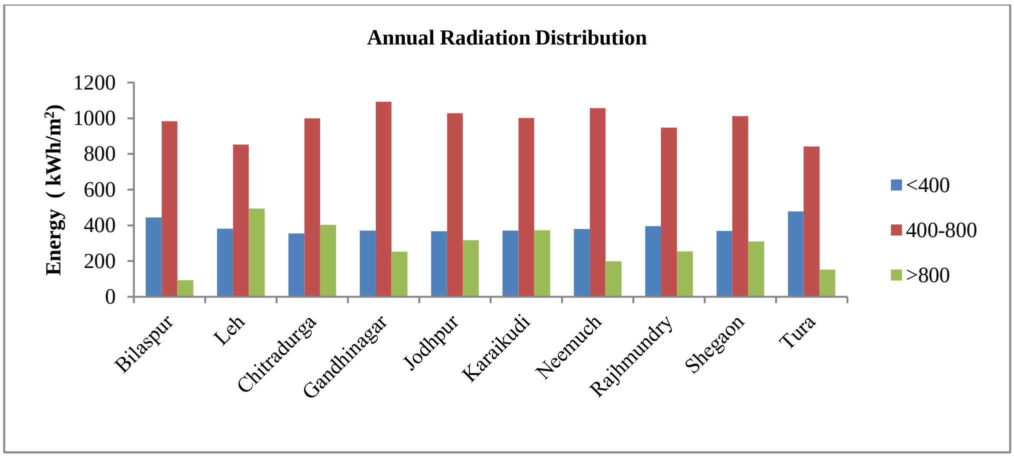

Fig. 12: Annual Distribution of Radiation at Various Irradiance Levels

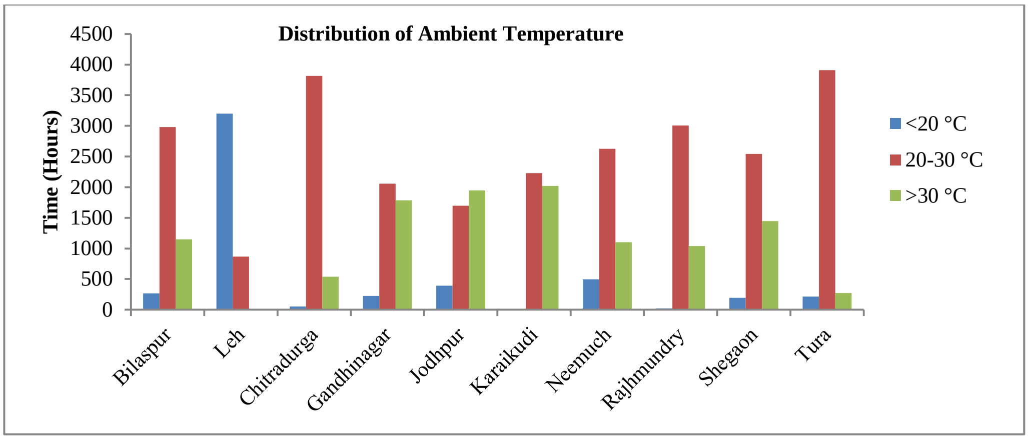

Fig. 13: Annual Day Time Temperature Distribution

3.12 Comparison of Annual Energy Generation from Various PV Technologies for the Selected Locations

The annual energy yield of four commercially available PV technologies is studied and compared at ten different geographical location in India, which are depicted in figure-14.The CdTe PV technology is estimated to have highest annual energy generation in all the places in comparison to other technologies in terms of unit installation capacity due to its better response to low irradiance and low temperature coefficient of power. The PV technology HIT is estimated to have highest annual energy generation in terms of unit collector area of the collector due to its highest efficiency among the four PV technologies selected. However keeping in mind the recent development in the efficiency of crystalline silicon technology it can be concluded that, mC-Si can also be a promising technology in Indian climate condition in order to get maximum energy output from unit area of installation.

The estimated levelised cost of energy is presented in figure-15. In terms of levelised cost of energy the technology mC-Si estimated to be having the lowest among the four selected technologies mainly due to its lowest capital cost coupled with better generation in all climatic conditions. The annual average generation from 1.0kW installation capacity in case of mC-Si varies from 1378 kWh to 1698 kWh from the lowest to the highest solar potential location. Similarly in case of CdTe it varies from 1417 kWh to 1702 kWh, for a-Si it varies from 1392 kWh to 1680 kWh and for the highest efficiency technology HIT taken for this study it varies from 1383 kWh to 1698 kWh. In the present scenario it seems mC-Si is the sole winner in terms of economic benefits. Accordingly, the prospect for market penetration of other technologies can happen only when there is a technology evolution in terms of low cost.

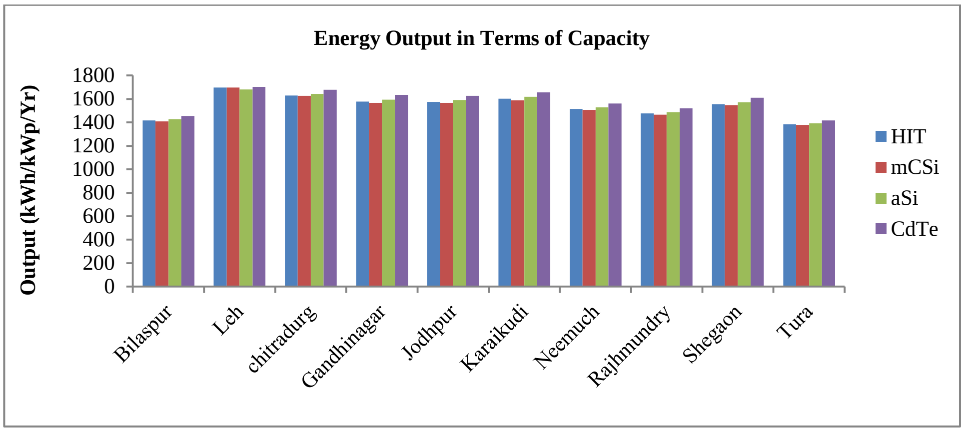

Fig.14: Energy Yield From Four PV Technologies

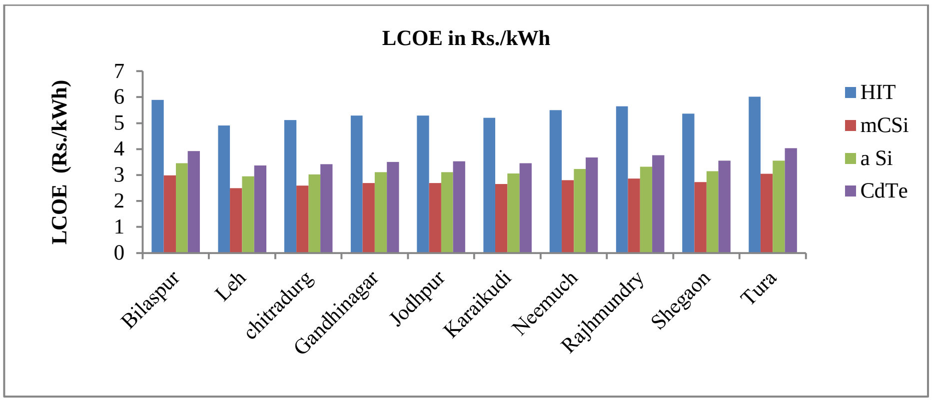

Fig.15 LCOE for Four PV Technologies

4. Conclusion

The ground measured solar resource analysis gives a broad picture of the kind of solar resource available in ten selected locations of India representing different climatic conditions prevalent in the country. The irradiance and temperature distribution throughout the year is analysed to indicate the most frequent condition in each location. Further, the annual energy generation and LCOE is estimated for four PV technologies available commercially in the market for the above ten locations. From the above study, it is concluded that, the annual energy generation from CdTe has been observed to be highest for all locations because of its low temperature co-efficient and better response at low irradiance, at Leh the energy generation from HIT is almost same as from CdTe. For places like Tura and Bilaspur, where the amount of radiation received at low irradiance level, thin film technologies are looking promising in terms of energy generation compared to mC-Si Technologies. It is also observed that HIT technology shows highest LCOE in all ten geographical locations in India and mC-Si shows lowest LCOE in ten different climatic zones in India due lowest installation cost.

Based on the already available solar resource map of India, which suggests that, most of the solar potential exists in the western and southern part of India and accordingly most of the present solar installations are located in these regions. The energy generated from these solar plants is consumed in various parts of the country. Although, the interstate transmission charges are presently not applicable for energy generated from solar power plants, this is certainly a cost to the country which has been socialized. Geographically distributed solar installations will certainly have the advantage of minimizing the transmission loss. This study will provide important information for all the stakeholders of PV industry to take an informed decision on selection of a PV technology for a particular location.

5. Acknowledgements

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6. Reference

Carr, A.J., Pryor, T.L., 2004. A comparison of the performance of different PV module types in temperate climates. Solar Energy 76 (1–3), 285–294. https://doi.org/10.1016/j.solener.2003.07.026.

CERC (Terms and Conditions for Tariff determination from Renewable Energy Sources) Regulations, 2017. http://www.cercind.gov.in/2017/regulation/Noti131.pdf.

Chakraborty, S., Sadhu, P., 2015. Technical mapping of solar photovoltaic for the Coal City of India. Renewables: Wind, Water, and Solar, 2(1). doi:10.1186/s40807-015-0013-1.

Cucchiella, F., D'Adamo, I., 2012. Estimation of the energetic and environmental impacts of a roof mounted Building- integrated Photovoltaic system. Renewable and Sustainable Energy Reviews 16, 5245-5259. https://doi.org/10.1016/j.rser.2012.04.034.

Dash, P.K., Gupta, N. C., Rawat, R., Pant, P.C., 2017. A novel climate classification criterion based on the performance of solar photovoltaic technologies. Solar Energy 144, 392-398. https://doi.org/10.1016/j.solener.2017.01.046.

Dash, P.K., Gupta, N.C., 2015. Effect of temperature on power output from different commercially available photovoltaic modules. Int. J. of Engineering Research and Applications 5(1), 148-151.

Huld, T., Suri, M., Dunlop, E. D., 2008. Geographical variation of the conversion efficiency of crystalline silicone photovoltaics modules in Europe. Progress in Photovoltaics: Research and application 16 (7), 595-607. https://doi.org/10.1002/pip.846.

Huld, T., Gottschalg, R., Beyer, H.G., Topicˇ, M., 2010. Mapping the performance of PV modules, effects of module type and data averaging. Solar Energy 84 (2), 324–338. https://doi.org/10.1016/j.solener.2009.12.002.

https://www.alibaba.com (accessed on January, 2018)

Lim, J. L., Woo, S. C., Jung, T. H., Min, Y. K., Won, C. S., Ahn, H. K., 2013. Analysis of factor on the temperature effect on the output of PV module. Transactions of the Korean Institute of Electrical Engineers 62 (3), 365-370. DoI: 10.5370/KIEE.2013.62.3.365.

Makrides, G., Zinsser, B., Schubert, M., Georghiou, G.E., 2014. Performance loss rate of twelve photovoltaic technologies under field conditions using statistical techniques. Solar Energy 103, 28–42. https://doi.org/10.1016/j.solener.2014.02.011.

Ministry of New and Renewable Energy. http://www.mnre.gov.in (assessed on June, 2018).

National Institute of Wind Energy. http://niwe.res.in (assessed on June, 2018).

Pavlovic, T. M., Milosavljevic, D. D., Mirjanic, D., Pantic, L. S., Radonjic, I. S., Pirsl, D., 2013. Assessments and perspectives of PV solar power engineering in the Republic of Srpska (Bosnia and Herzegovina). Renewable and Sustainable Energy Reviews 18, 119–133. https://doi.org/10.1016/j.rser.2012.10.007.

Rawat, R., Kaushik, S.C., Sastry, O.S., Singh, Y.K., Bora, B., 2016. Energetic and exergetic performance analysis of CdS/CdTe based photovoltaic technology in real operating conditions of composite climate. Energy Convers. Manage. 110, 42–50. https://doi.org/10.1016/j.enconman.2015.11.069.

Reindl, T., Ouyang, J., Khaing, A. M., Ding, K., Khoo, Y. S., Walsh, T. M., Aberle, A.G., 2012. Investigation of the Performance of Commercial Photovoltaic Modules under Tropical Conditions. Japan Journal of Applied Physics 51, 10NF11. https://doi.org/10.1143/JJAP.51.10NF11.

Santana-Rodŕiguez, G., Vigil-Galan, O., Jimenez-Olarte, D., Contreras-Puente, G., Monroy, B.M., Escamilla-Esquivel, A., 2013. Evaluation of a grid-connected photovoltaic system and in-situ characterization of photovoltaic modules under the environmental conditions of Mexico City. Revista Mexicana de Fisica 59(2), 88–94.

Skoplaki, E., Palyvos, J.A., 2009. On the temperature dependence of photovoltaic module electrical performance; A review of efficiency/power correlations. Solar Energy 83 (5), 614–624. https://doi.org/10.1016/j.solener.2008.10.008.

Swift, K. D., 2013. A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States. Renewable Energy 57, 137-143. https://doi.org/10.1016/j.renene.2013.01.011.

Tossa, A.K., Soro, Y.M., Thiaw, L., Azoumah, Y., Sicot, L., Yamegueu, D., Lishou, C., Coulibaly, Y., Razongles, G., 2016. Energy performance of different silicon photovoltaic technologies under hot and harsh climate. Energy 103, 261–270. https://doi.org/10.1016/j.energy.2016.02.133