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Solar PV Energy Generation Map of Karnataka, India

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Abstract

A massive plan has been drawn by the Karnataka state of India to initiate several solar power plants at different locations. In view of this, it is of great help to have reliable estimation on solar PV energy generation. Four solar PV power plants in Karnataka state are fully operational installed by Karnataka Power Corporation Limited (KPCL). They are located at Kolar, Belgaum and Raichur with 3 MW capacity each and at Mandya with 5 MW capacity. In the present study, using ground mounted weather station data solar power generation has been estimated and compared with actual generation for two consecutive years of 2012 and 2013 for one location initially, namely 3 MW Kolar Solar PV Plant. The procedure is repeated for rest of the plants. The simulated results have been corrected with ground mounted weather data. After such corrections, the simulated results have been compared with the actual energy generation of the four plants. Results showed a close match with a small deviation of about 5%. The model then applied throughout the state for every 0.25 degree station intervals in a grid manner. The annual energy generation obtained for the state varies from 1.53 to 1.73 MUs/MW. Central and south eastern part of the state are found to yield significantly higher solar power generation as compared to the northern part and south western part of Karnataka. Interestingly, north western part of Kodagu district has shown the least potential of 1.53 MUs/MW as compared to other parts. This can be attributed mainly due to low irradiation and high temperature condition at this location. The energy generated map from our study will be useful and helpful for both solar developers and decision makers of Karnataka state.

Keywords

Solar Energy Generation Map, Solar Photovoltaic (PV) Plant, Karnataka, PVSyst, Meteonorm, KPCL, Kolar, Belgaum, Raichur, Mandya

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1. Introduction

Indian energy industry is experiencing a major reform in power sector. As a part of Jawaharlal Nehru National Solar Mission (JNNSM), 175 GW worth of power plants from different renewable sources is expected to be added towards mitigation of climate change and to meet power requirement of the country. After witnessing 1 GW worth of solar PV plants in Gujarat, solar PV technology has emerged as a reliable renewable energy source in India. JNNSM has put a major thrust on installation of a total 100 GW capacity of solar photovoltaic (PV) plants. Karnataka is a rich state in terms of annual quantity and availability of solar radiation. The state is blessed with good amount of solar irradiation that varies from 5.4 to 6.2 kWh/m^2/day [1].

There are two major bottlenecks towards accurate solar energy yield estimation-availability of reliable weather data and reference generation from a utility scale power plant close to the proposed new location of installation. Satellite based weather data, which is being used widely, has limitations like incapable to differentiate between clouds and snow *i.e*. objects reflect similar spectrum, close to mountains, water bodies etc. and they need atmospheric data for image analysis that has its inherent errors. The free source of solar radiation data is from the map prepared by Ministry of New and Renewable Energy (MNRE), Government of India in collaboration with Meteonorm [2]. However, high temperature of air causes significant loss in power produced at solar PV module level and plays a vital role in energy yield. This data is not available in the database. On the other hand, a lot of work has been reported on preparation of solar potential (radiation) map using GIS for more than a decade. Solar generation maps with the help of theoretical models are developed by using softwares like PVSyst, PV GIS, RET Screen etc., and have also been used widely for simulating plant losses [3]-[9].

In India, a detailed report is prepared for Central Electricity Regulatory Authority (CERC) [10]. The report includes solar PV generation for different locations and by using different module technologies. The simulated results are compared with generation data obtained from couple of India's first few grid-connected power plants for different locations. However, the software model was not validated with ground data and errors in annual performance of plant are reported to be as high as 20%. Ganguli and Singh [11] theoretically estimated solar power near Patiala, Punjab. Bharathkumar and Byregowda [12] carried out a comparative study of SCADA data of plant with PVSyst for 5 MW solar plant installed by Karnataka Power Corporation Limited (KPCL) at Belakavadi in Mandya district of Karnataka. Their results indicated an error in actual and simulated plant output in the range of −23% to 9%. Some of the other researchers have undertaken similar work; however, no ground validation has been reported. Harinarayana and Kashyap [13] prepared solar PV energy generation map of India and for three states Gujarat, Andhra Pradesh and Telangana. They used Meteonorm data and PVSyst software along with Google Earth and Surfer. Mitavachan, Gokhale and Srinivasan [14] evaluated performance of KPCL's 3 MW SPV plant installed at Kolar. Joshi [15] prepared solar radiation potential map using GIS.

In most of the earlier studies, the results of studies based on weather data received through satellite. They are only useful in absence of actual historical solar power plant generation data, at the location of interest. Our observation is that most of the time satellite based data are employed with software based model without validation with actual generation from ground mount solar PV plant. This gives rise to large difference between software based model and actual energy generation and reduces the degree of confidence for decision making.

2. Methodology

In the present study, we have used monthly weather data from National Institute of Wind Energy (NIWE, formerly Centre for Wind Energy Technology—CWET) for the years 2012 - 2014 from three locations in Karnataka viz. Belgaum (Lat. 16.42˚N, Long. 74.79˚E), Chitradurga (Lat. 14.22˚N, Long. 76.43˚E) and Gulbarga (Lat. 17.32˚N, Long. 76.85˚E). This data is used for four solar PV plants. **Table 1** provides information about plant commissioning dates for different solar PV plants of KPCL.

In the following, the procedure followed for Kolar PV plant is presented. A software based model with a plant design for 3 MW solar PV plant near the village Yalesandra, District Kolar, installed by Karnataka Power Corporation Limited (KPCL), was prepared in PVSyst 6.3.9 The parameters considered for developing solar PV plant model in PVSyst software are received from KPCL and are as summarized in **Table 2**.

3. Plant Electrical Configuration Used for Simulation

The Yalesandra SPV plant is a 3 MW (DC) capacity solar power plant. It is further divided into 3 segments of 1 MW (DC) each. This is further divided into four segments of 250 kW (DC) capacity of solar PV array each. The

Table 1. Solar power plants of KPCL with locations and years of commissioning details.

Sr. No.	Plant Name	Location	Year of Commissioning
1	Kolar 3 MW SPV Plant	Village Yelasandra, Dist. Kolar, Karnataka Lat. 12˚53'35.24"N, Long. 78˚09'55.94"E	Nov. 2009
2	Belgaum 3 MW SPV Plant	Village Itnal, Dist. Belgaum, Karnataka Lat. 16˚26'05.31"N, Long. 74˚40'26.39"E	Nov. 2009
3	Raichur 3 MW SPV Plant	Village Yapaladinni, Raichur, Karnataka Lat. 16˚14'51"N, Long. 77˚26'35"E	Feb. 2012
4	Mandya 5 MW SPV Plant	Village Belakavdi, Dist. Mandya, Karnataka Lat. 12˚15'17.79"N, Long. 77˚07'22.17"E	July 2012

Table 2. Detailed Parameters of 3 MW Kolar Power Plant, Kolar district [14] (The table is prepared with collective information [14]).

Sr. No.	Parameters	Values
General Information		
1	Location	Yalesandra, Kolar District, Karnataka State of India
2	Plant Details	3 MW Solar PV Grid-Fed Power Plant
3	Co-ordinates	12˚53' & 78˚09'
4	Date of Commissioning	27th December, 2009
5	Plant Area	5.4 Acres
PV Module Information		
6	Solar PV Module Technology	Mono-Crystalline
7	Model	S6-60 Series
8	Power at Maximum Power Point (Pmp), Wp	225 and 240 respectively
9	Voltage at Maximum Power Point (Vmp), V	28.63 and 29.62 V (DC) respectively
10	Current at Maximum Power Point (Imp), A	7.93 A and 8.12 A (DC) respectively
11	Open Circuit Voltage (Voc), V	37.50 and 37.62 V (DC) respectively
12	Short Circuit Current (Isc), A	8.52 A and 8.55 A (DC) respectively
13	Module Dimensions (LXBXH), mm	1657X987X42
14	NOCT, ˚C	45
15	Weight, kg	19
16	No., Type and Arrangement of Cells	60, Mono-Crystalline, 6X10 Matrices
17	Glass Type	3.2 mm Thick, Low Iron, Tempered Glass
18	No. of Cells per Solar PV Module	60
19	No. of Solar PV Modules	10,152 No. of 225 Wp 3216 No. of 240 Wp
20	No. of Solar PV Modules in a String	24 No.
21	Name – Plate Capacity of Solar Inverter	250 kW
22	Tilt Angle of Modules	15˚
Power Conditioning Units/Solar Inverters		
23	Make	Bonfiglioli
24	No. of Solar Inverters	12
25	No. of Solar PV Strings per Inverter	45 - 46 (Total 557 Strings)
26	No. of Strings per MW	1) 181 No. (1st MW from 240 Wp Solar PV Modules) 2) 188 No. (2nd and 3rd MW from 225 Wp Solar PV Modules)
27	HT Transformer and Switchgear for Evacuation	1.25 MVA for each 1 MW Solar PV Array

250 kW DC array is served by one inverter of 250 kW capacity. Thus, there are twelve 250 kW inverters. Moreover, depending upon the wattage of modules, 1 MW plant has either 45 or 46 strings of solar PV modules, each of which is having 24 solar PV modules. Output from four inverters 0.415 kV is stepped to 11 kV through one 1.25 MVA transformer. There are three such transformers in the plant. The power is evacuated into state electricity grid at 11 kV. **Figure 1** provides schematic view of this power plant.

For simulation of energy generation weather data received from ground mount weather station at Chitradurga, for the year 2012 are used. For the development of first model, input losses are kept as it is, in PVsyst model (with default values). PVSyst output is 10.3% more compared to actual plant output. Design details with annual (%) loss due to soiling, cable losses and percentage uptime of the plant. Additionally, complete plant model is prepared using layout of the plant as obtained from Google Earth. Average distance between solar modules and inverter is about 36 m and it is about 40 m from inverter to transformer. All the details pertaining to all the four power plants like availability of grid, plant failure, plant layout etc. were confirmed by competent authority of KPCL. Google Earth image of the site is presented in **Figure 2** whereas shading scenes prepared to simulate plant arrangement are presented in **Figure 3** and **Figure 4**.

This model (with all percentage losses) is taken for simulating energy generation at different locations for different years. Next simulation is done with percentage loss recorded at Kolar plant location.

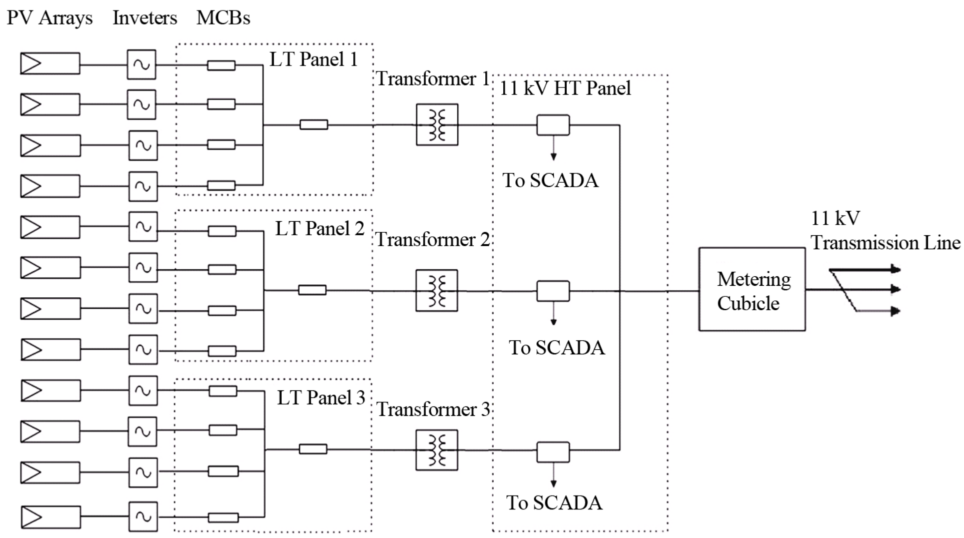

Figure 1. Schematic diagram of 3 MW solar power plant at village Yalesandra, Dist. Kolar (Kolar Plant), Karnataka [14].

Figure 2. Google earth image of Kolar SPV plant.

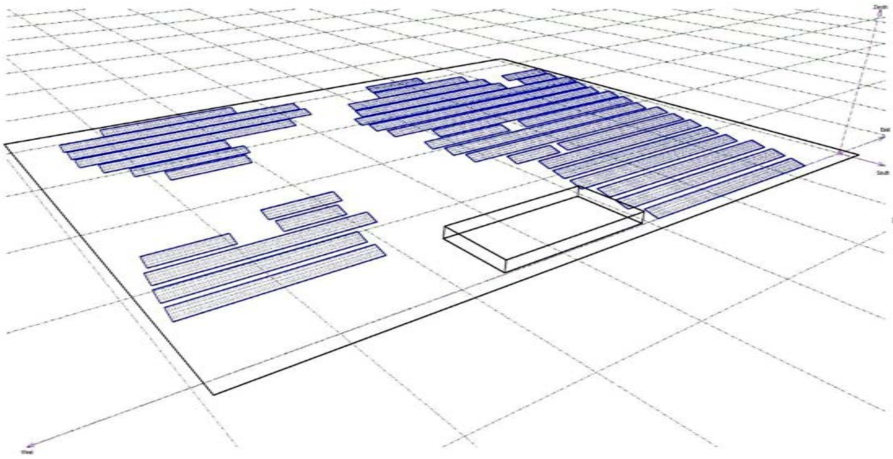

Figure 3. Kolar plant design developed using PVSyst.

The model developed, is used comparing with the actual generation received for the years 2012 and 2013 for three other plants *i.e*. 3 MW SPV plant at Belgaum and Raichur district and 5 MW SPV plant at Mandya district of Karnataka. Uptime losses (around 6%) were deducted from the PVSyst simulated output and compared with actual plant output for different year. After receiving satisfactory results, the model is run with Meteonorm weather data to predict generation for all the plant locations mentioned above and average deviation from respective plant generation data with respect to actual generation taken as correction factor of energy predictions from Meteonorm. The PVSyst refined model with Meteonorm data is then applied for all the locations across Karnataka state with 0.25˚ interval in a grid fashion. The annual energy generation is corrected by applying correction factor. The corrected simulated energy values are plotted using Surfer 10 software and generation maps for all 300 locations are prepared. For the justification of higher and lower energy generation at such locations, annual average irradiance and annual average ambient temperature maps are also prepared.

4. Results & Discussion

Figure 5 summarizes the validation of PV plant model with details, actual energy recorded at site, total input solar energy, simulated plant output, uptime losses (losses due to non-availability of grid, planned/un-planned shutdowns etc.) and deviation observed during model development and validation with different plant outputs for different years and for different locations.

Figure 6 provides the loss profile validated and modified based on the site design parameters used for simulation.

In the first simulation with PVSyst default values, 10.3% deviation was observed with actual data from Kolar plant, the deviation dropped to 0.7% and 0.2% for the years 2012 and 2013. An annual degradation of 0.5% from the total simulated output has been considered as uniform discounting factor for all the plants.

When same model was applied at different locations and different year, different errors were reported which may be attributed to different topography, different weather conditions and different plant design. However, average error percentages were found to be −4.4% *i.e*. simulated output is less than the actual plant output (**Table 3**). This is found well within the limits.

Later on, the same model is applied for all the four locations for the years 2012-2013 using Meteonorm data and simulated output is compared with actual generation data of respective plant for respective year. Good match is observed for Meteonorm data based simulation for all four plants of the state for the year 2013. Average percentage error is found to be −4.35%. The error is incorporated to modify the simulated plant generation from Meteonorm. Errors in simulated plant output through Meteonorm data are studied with actual plant generation data. Summary of the exercise is shown in **Table 3**.

Figure 7 shows the solar PV energy potential across Karnataka state of India. It can be easily estimated about the locations having higher and lower solar PV energy potential. From the map the installers and developers can get crucial information for installing and designing solar PV plants. Large deviation is observed for the year 2012 and small deviation is observed for the year 2013. This may be because of proper operation and mainten-

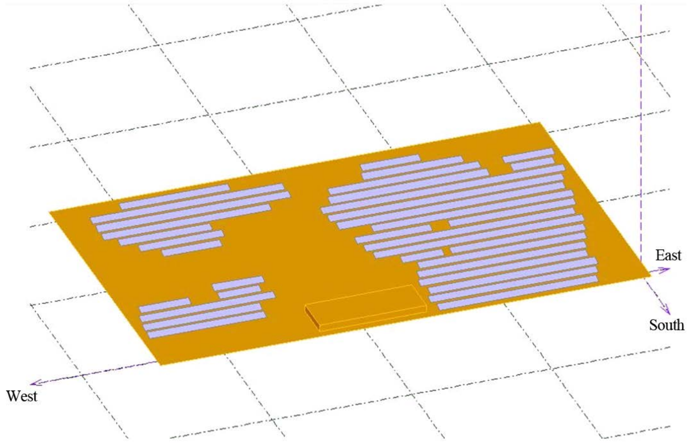

Figure 4. Shading analysis development using PVSyst.

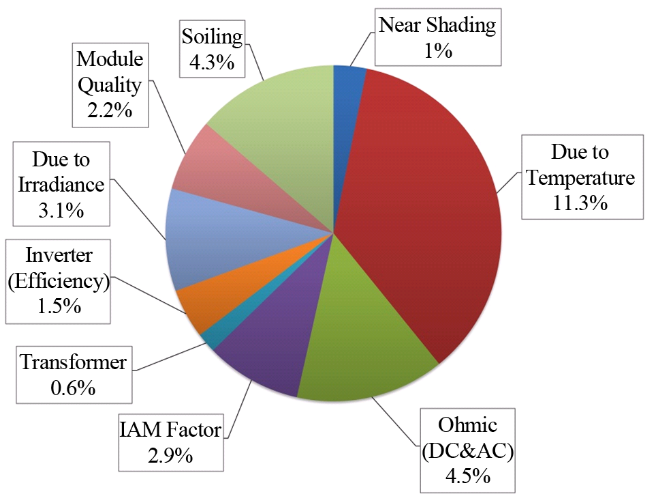

Figure 5. Energy loss profile based on near shading, temperature, irradiation, ohmic, IAM factor, transformer, inverter, soiling and module quality.

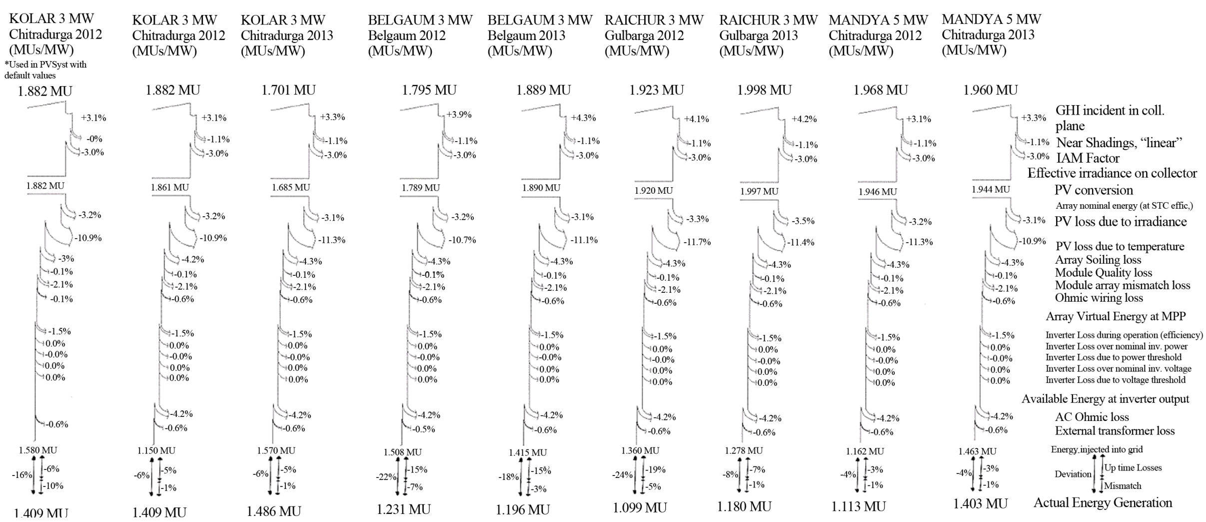

Figure 6. Results of development and validation of the plant model and analysis along with energy losses.

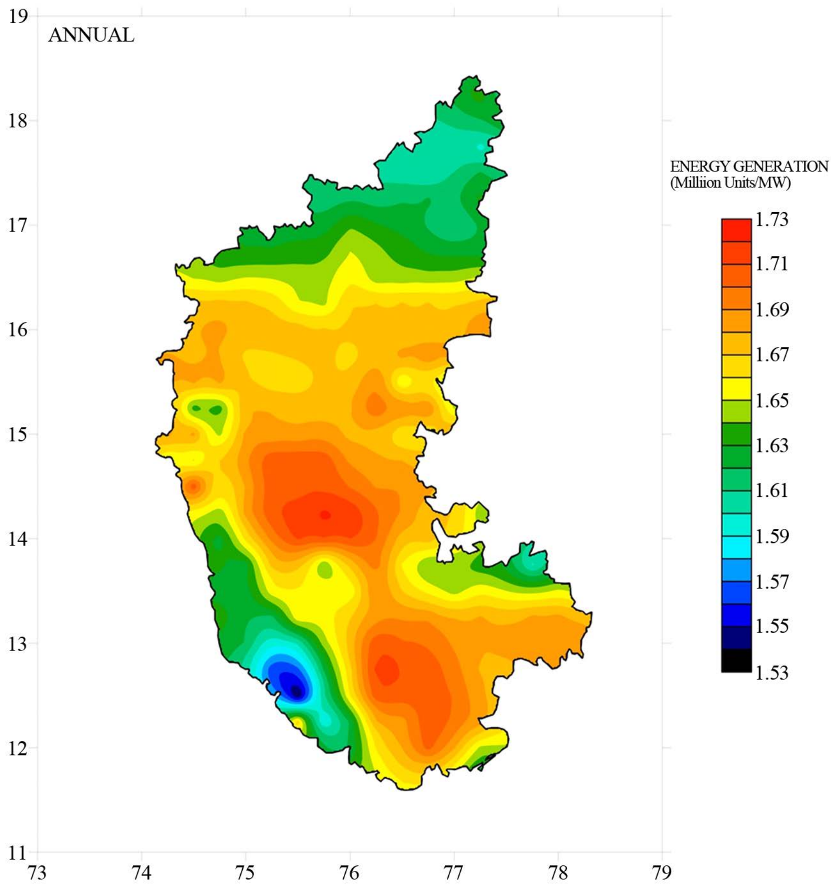

Figure 7. Annual solar PV energy generation potential for Karnataka state based on the irradiation and weather parameters.

Table 3. KPCL power plant details of actual energy generation and comparison with our simulated data with deviation.

Plant Name	Year	Energy Generation (MUs)		Deviation	Average deviations of two years
		Actual	Simulation using data from Meteonorm		
Kolar3 MW	2012	4.07	4.45	−9.34%	−4.78%
	2013	4.44	4.45	−0.23%	
Belgaum 3 MW	2012	3.49	3.71	−6.30%	−3.97%
	2013	3.65	3.71	−1.64%	
Raichur 3 MW	2012	3.29	3.55	−7.90%	−4.09%
	2013	3.54	3.55	−0.28%	
Mandya 5 MW	2013	7.02	7.34	−4.56%	−4.56%

ance of the power plants such as proper cleaning techniques and replacing faulty components.

It is observed that solar energy potential depends on both radiation and temperature variation. The solar PV energy potential maps for twelve months (from January to December) for the state are also prepared using Surfer 10, can also be seen in **Figure 8**.

Figure 9 shows the annual average irradiance for the Karnataka State which helps to understand the solar energy dependence on irradiation.

Figure 10 provides average annual temperature for the Karnataka State. This also helps to understand the negative effect of temperature on solar PV energy generation.

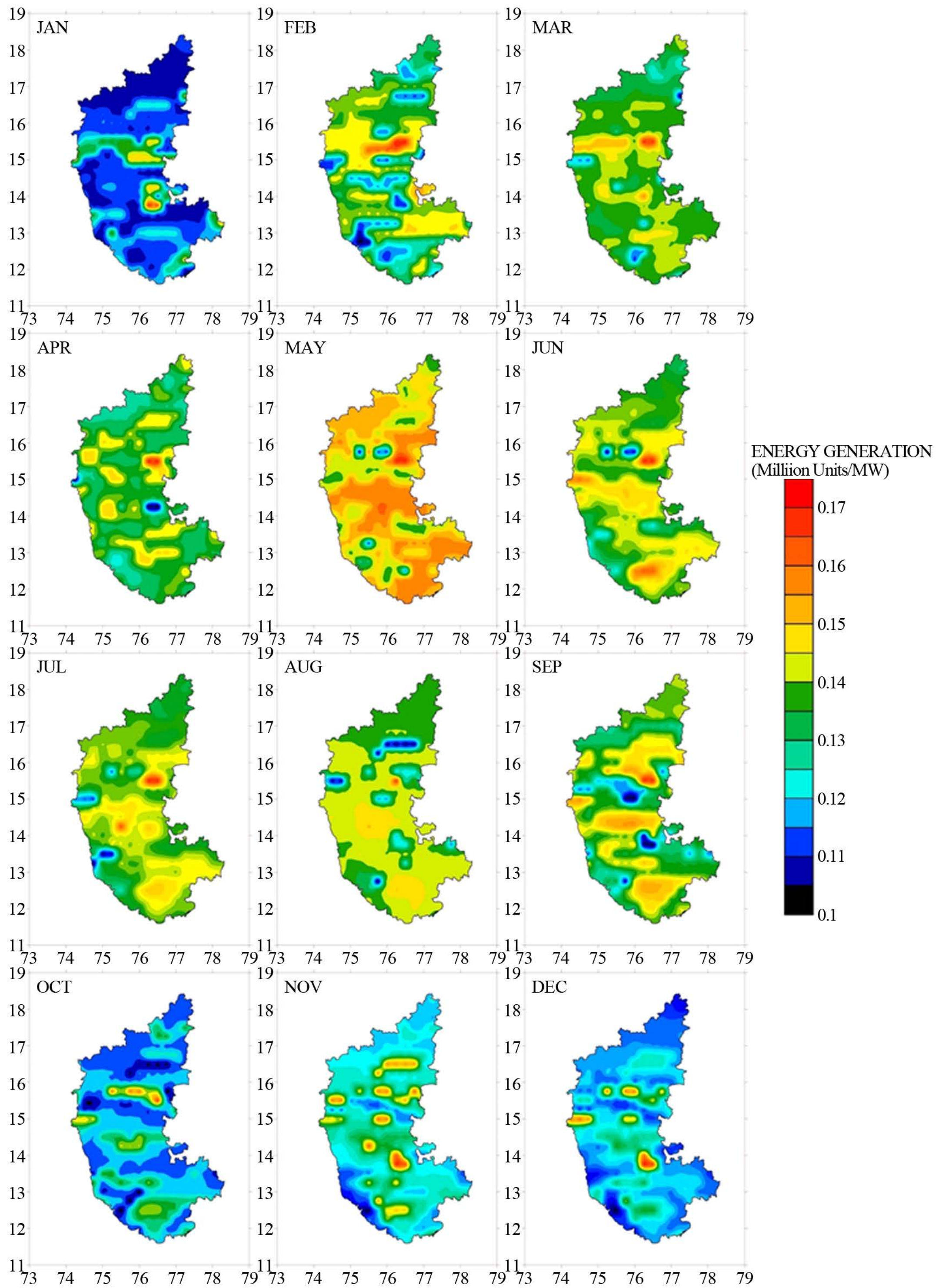

Figure 8. Monthly average solar PV energy generation potential for Karnataka state.

5. Conclusions

The present study deals with Solar PV energy generation potential for the Karnataka state. Both annual energy generation and month wise energy generation maps are prepared. The simulation results are closely matching with the actual energy generation data of existing power plants. We have considered the data from four solar PV

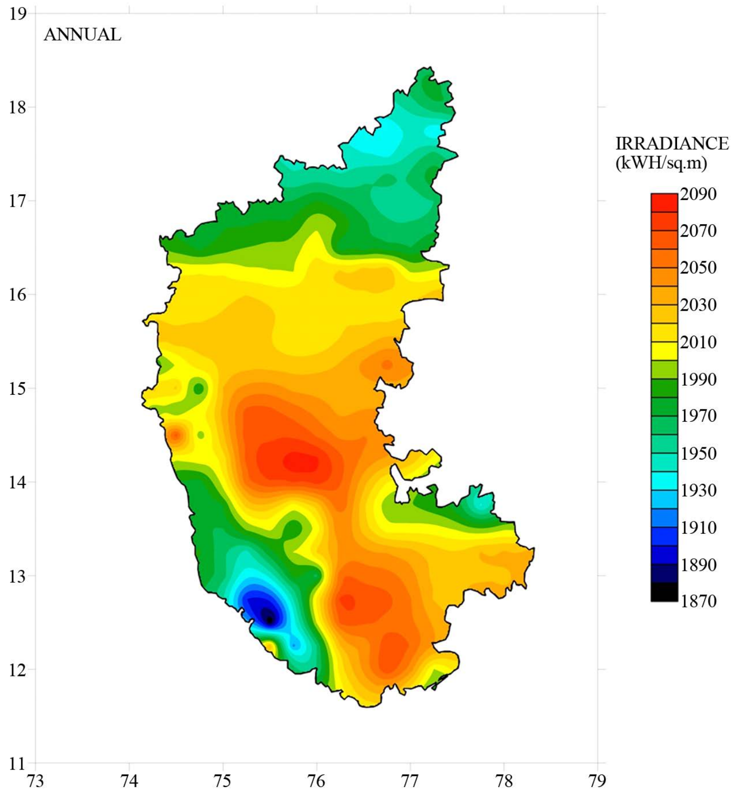

Figure 9. Annual average irradiation map for Karnataka state.

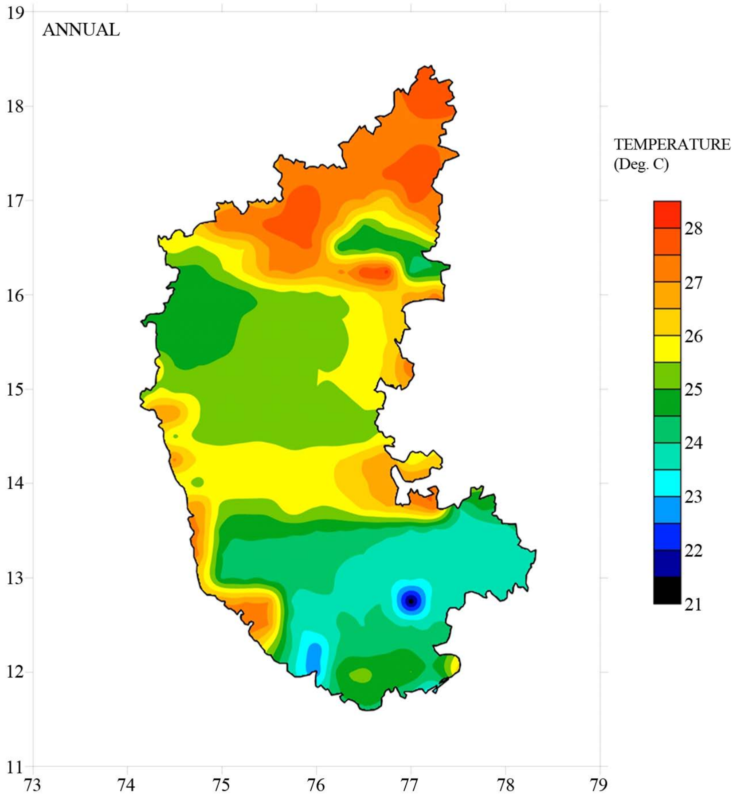

Figure 10. Annual average temperature map for Karnataka state.

power plants already installed and commissioned a few years back. Simulation data are validated from comparison with actual generation and less than 5% error could be achieved. It is observed that majority of Karnataka state has very high solar PV energy potential except small area in Kodagu district located in SW part of the state. Here the potential is relatively less compared to other districts due to relatively low solar radiation and relatively high temperature.

Generation map prepared here is valid for fixed tilt type of structures and for non-concentrating type of solar PV Si-Crystalline modules. Further, the model is developed to replicate energy generation received by Kolar plant by simulating electrical design and site layout of the plant. With different plant layouts, technology, selection of components, grid outage conditions, cleaning cycle etc., different results may be obtained.

Our study results should be quite useful to the decision makers and also equally to the solar developers to optimally demarcate the area for solar power plants. It should help in choosing the area to create large power plants, for example solar parks etc. Choosing a large energy generation area is always advantageous from economics point of view.

Solar PV industry is advancing at fast pace. With newer technologies, higher efficiency modules, use of tracking mechanisms etc., better results are expected to be achieved. Further studies should be carried out in similar manner with advanced technology.

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References

[1] Karnataka Solar Policy 2014-2021. http://ireeed.gov.in/policydetails?id=54#

[2] India Solar Resource Maps. http://mnre.gov.in/sec/solar-assmnt.htm

[3] Broesamle, H., Mannstein, H., Schillings, C. and Trieb, F. (2001) Assessment of Solar Electricity Potentials in North Africa Based on Satellite Data and a Geographic Information System. *Solar Energy*, **70**, 1-12. https://isites.harvard.edu/fs/docs/icb.topic668790.files/Discussion%202%20Readings/Solar%20Radiation%20in%20Africa.pdf http://dx.doi.org/10.1016/S0038-092X(00)00126-2

[4] Hammera, A., Heinemann, D., Hoyera, C., Kuhlemanna, R., Lorenza, E., Mullera, R. and Beyer, H.G. (2003) Solar Energy Assessment Using Remote Sensing Technologies. *Remote Sensing of Environment*, **86**, 423-432. http://www.uni-oldenburg.de/fileadmin/user_upload/physik/ag/ehf/enmet/publications/solar/journal/2003 http://dx.doi.org/10.1016/S0034-4257(03)00083-X

[5] Suri, M. and Hofierka, J. (2004) A New GIS-Based Solar Radiation Model and Its Application to Photovoltaic Assessments. *Transactions in GIS*, **8**, 175-190. http://www.readcube.com/articles/10.1111%2Fj.1467-9671.2004.00174.x?r3_referer=wol&tracking_action=preview_click&show_checkout=1&purchase_referrer=onlinelibrary.wiley.com&purchase_site_license=LICENSE_DENIED http://dx.doi.org/10.1111/j.1467-9671.2004.00174.x

[6] Khare, V., Nerma, S. and Baredar, P. (2013) Status of Solar Wind Renewable Energy in India. *Renewable and Sustainable Energy Reviews*, **27**, 1-10. http://ac.els-cdn.com/S136403211300395X/1-s2.0-S136403211300395X-main.pdf?_tid=bc955690-972f-11e5-b8e3-00000aacb362&acdnat=1448866878_fa12eac4106d050db1f5981956adbff6 http://dx.doi.org/10.1016/j.rser.2013.06.018

[7] Goswami, D. (2012) India's Solar Sunrise. *Renewable Energy Focus*, **13**, 28-30. http://dx.doi.org/10.1016/S1755-0084(12)70037-6

[8] Sharma, P. and Harinarayana, T. (2013) Solar Energy Generation Potential along National Highways. *International, Journal of Energy and Environmental Engineering*, **4**, 16. http://dx.doi.org/10.1186/2251-6832-4-16

[9] Harinarayana, T. and Vasavi K.S.V. (2014) Solar Energy Generation Using Agriculture Cultivated Lands. *Smart Grid*

and Renewable Energy, **5**, 31-42. http://dx.doi.org/10.4236/sgre.2014.511025

[10] Performance of Solar PV Plants in India, 2011. www.cercind.gov.in

[11] Ganguli, S. and Singh, J. (2010) Estimating the Solar Photovoltaic Generation Potential and Possible Plant Capacity in Patiala. *International Journal of Applied Engineering Research*, *Dindigul*, **1**, No. 2. http://www.ipublishing.co.in/jarvol1no12010/EIJAER1024.pdf

[12] Bharatkumar, M. and Byregowda, H.V. (2014) Performance Evaluation of 5 MW Grid-Connected Solar Photovoltaic Plant Established in Karnataka. *International Journal of Innovative Research in Science*, *Engineering and Technology*, **3**. http://www.ijirset.com/upload/2014/june/88_Performance.pdf

[13] Harinarayana, T. and Kashyap, J.K. (2014) Solar Energy Generation Potential Estimation in India and Gujarat, Andhra, Telangana States. *Smart Grid and Renewable Energy*, **5**, 275-289 www.scirp.org/journal/PaperDownload.aspx?paperID=51455 http://dx.doi.org/10.4236/sgre.2014.511025

[14] Mitavachana, H., Gokhale, A. and Srinivasan, J. (2011) A Case Study of 3-MW Scale Grid-Connected Solar Photovoltaic Power Plant at Kolar, Karnataka. Report by Divecha Centre for Climate Change, Indian Institute of Science. www.dccc.iisc.ernet.in/3MWPV_Plant.pdf

[15] Joshi, J. (2013) A Research Study on Developing Solar Potential Map Using GIS. *International Journal of Emerging Trends and Technology in Computer Science*, **2**. www.ijettcs.org/Volume2Issue3/IJETTCS-2013-06-21-113.pdf