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DIRECT CONVERSION OF SOLAR ENERGY INTO ELECTRIC ENERGY

Estimation of Bright Roof Areas for Large Scale Solar PV Applications to Meet the Power Demand of Megacity Hyderabad[1]

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Abstract—Hyderabad is reeling under a severe power crisis aggravated due to the recent bifurcation of the state of Andhra Pradesh. Telangana state needs more power than residual Andhra Pradesh due to greater demand from its Industrial and Agricultural consumers. The installed capacity (established as well as under construction) of power plants under Telangana Power Generation Corporation (TSGENCO) includes 2282.5 MW of thermal coal based power, 2081.76 MW of hydro power and 1 MW solar power. As more than 50% of the power source is coal based, there exists a threat of fossil fuel depletion and enhanced Green House Gas (GHG) emissions. Solar electricity has the potential to offset these negative impacts. This paper concentrates on evaluating the roof top area required for solar power generation using Remote Sensing and GIS apart from developing an algorithm using analytical methods, to estimate the photo-voltaic system components required, for the total power requirement of Hyderabad city.

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1. INTRODUCTION

Megacity Hyderabad in southern part of India is going through a phase of power crisis over the last several years. Adding to its woes is the bitter wrangling for electric power between the newly formed Telangana and the now truncated Andhra Pradesh. The city is ridden with two to four hour power cuts per day and weekly power holidays for industries [1]. One of the major barriers for the economic development of developing countries is insufficient power supply [2]. Opting for renewable energy based power production especially solar photovoltaic will have a great impact in reducing the use of fossil fuels such as coal for power generation, thereby reducing emission of green house gases like CO_2 apart from overcoming the power shortage [3]. The government of India (GoI) has set itself a target of increasing solar power production to 100 GW by 2022 and 200 GW by 2050. With the Government of India implementing regulatory and policy interventions, solar power is expected to compete aggressively with conventional power by 2017. The solar potential of Telangana is very high as it has an average solar insolation of 5.12 kW h/m^2 and more than 300 days of sunshine. Government of Telangana (GoTS) intends to harness this potential by making use of the push given by the GoI [4]. In this regard GoTS is committed to promote solar roof top systems on domestic, industrial and commercial establishments apart from public buildings. It proposes to provide several incentives to both grid connected as well as off-grid solar rooftop projects apart from extending all incentives provided by GoI's Ministry of New and Renewable Energy (MNRE) and the Jawaharlal Nehru National Solar Mission. The policies mentioned above in brief highlight the possible scope of PV power plants in future. This has served as a motivation for this paper. The successful development and implementation of renewable energy projects however demands reliable assessment of implementable potential and economic feasibility especially when it includes building integrated applications [5]. The crucial factor however is the availability of bright open spaces for photo- voltaic (PV) applications [2]. It is felt that roof area calculation of a city is the essential input data for the application of building integrated solar PV systems and solar electricity generation [5]. This study aims to calculate the bright roof area needed in Hyderabad City to generate solar electricity, so as to meet the power demands of the city, through the use of grid interactive Solar PV systems. The roof area estimation also happens to be the basic input for understanding the solar thermal potential in buildings [6] and rain water harvesting potential [7]. The total electrical energy consumption in Hyderabad city is estimated, based on which a plausible PV sizing requirement for meeting the total electricity demand of the city is computed analytically. The siz-

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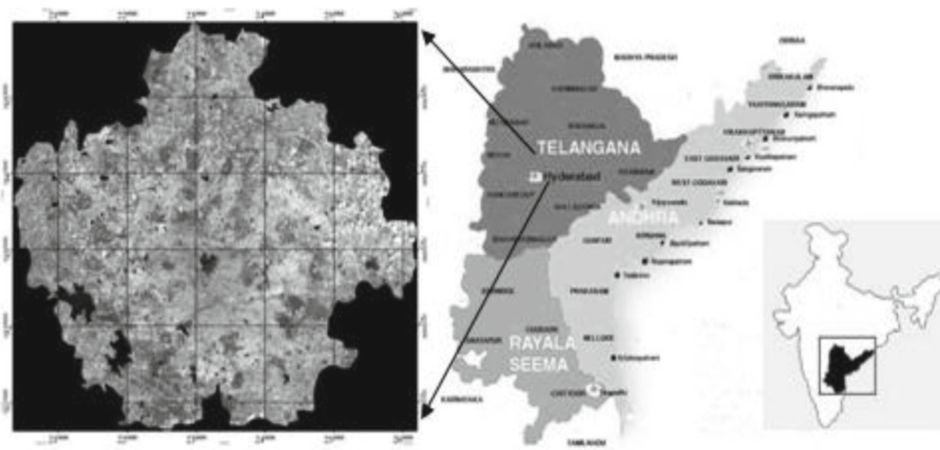

Fig. 1. Location of study area.

ing procedure for installation of photovoltaic modules for a 1MW solar power plant, which can be scaled up as per requirement is also included. The PV sizing methodologies available in the literature cover a large spectrum of approaches [8, 9]. Various studies undertaken earlier [10–12] have been referred and studied before finalizing the algorithms and equations used in this study.

2. DATA SOURCE, STUDY AREA AND METHODOLOGY

Hyderabad (78°28′27″ E and 17°22′31″ N) [REMOVED HYPERLINK FIELD]is currently the joint capital of the newly bifurcated state of Andhra Pradesh and Telangana, India. Hyderabad is situated on the Deccan plateau, located in North West of Andhra Pradesh (Fig. 1). It is one of the largest metropolitan cities in India with an area of 1905 square kilometers. As of 2011, the city had 6.809.970 residents and the metropolitan area comprised of 7.749.334 residents [13, 14] making it the fourth most populous city and the sixth most populous urban agglomeration in India. By 2015 the population in the city has risen to 9.507.434 and is shortly expected to cross the one crore mark. The maximum temperature during summer time reaches a high of 40°C and a low of 30°C. In winters, the mercury fluctuates between 14 and 22°C. According to Southern Power Distribution Company Limited [15] the power demand in Hyderabad ranges between 1700 MW and 2100 MW and peaks to even 2300 MW in summer.

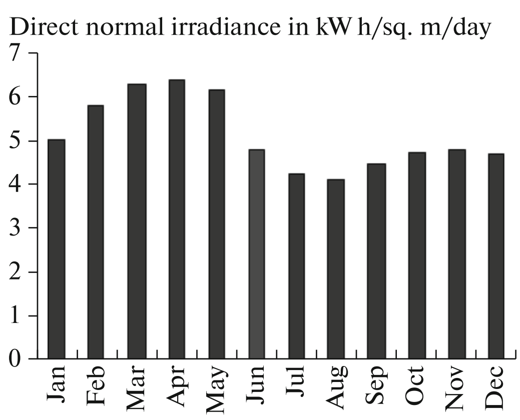

Fig. 2. Monthly variations in solar radiation received over Hyderabad City.

According to the 18th Electric Power Survey of India, the overall electrical energy requirement of the 13 mega-cities including Hyderabad City, in 2011–2012, amounts to 12% of the total electrical energy requirement of India as a whole. These 13 cities together housed nearly 7.5% of the country's population. The transmission and distribution (T and D) losses attributed to these cities was also far below the national average [16]. The survey made use of data furnished by state transmission utilities and discoms. Various city master plans were also considered to arrive at the growth in energy requirement. T and D losses were also taken into consideration.

2.1. Radiation Profile of the District

The annual mean global radiation was observed to be 5.12 kW h/m^2. The variations in the monthly mean radiation received in Hyderabad is shown in Fig. 2. For built up area identification and calculation, the Landsat 8 OLI data acquired on 28th December 2014 with a spatial resolution of 30 m was analyzed for this research. The scenes were selected based on the need to acquire records of the urban growth. The study area boundary was digitized from the topographic map using Arc GIS 9.2 software. Survey of India topographical sheets on 1 : 50.000 scale were used as reference data for rectification of satellite images and selection of Ground Control Points (GCPs).

2.1.1. Consumption patterns of Mega-Cities. The Central Electricity Authority (CEA) in its 18th Electric Power Survey (EPS) of Mega Cities has said that the total electrical energy requirement of the 13 cities accounted for 12% of the overall electrical energy

Table 1. The 11th, 12th and 13th plans extending from 2007–2012, 2012–2017 and 2017–2022, respectively

Electrical energy requirement at power station						
Million kW h						
	terminal year of			% total		
	11th plan	12th plan	13th plan	11th plan	12th plan	13th plan
Lucknow	4.840	6.796	9.074	4.4	4.3	4.2
Kanpur	3.046	4.023	5.131	2.8	2.6	2.4
Jaipur	3.905	6.743	10.683	3.5	4.3	4.9
Ahmedabad	7.862	11.133	16.097	7.1	7.1	7.4
Surat	8.029	11.053	15.225	7.3	7.0	7.0
Nagpur	2.311	3.193	4.820	2.1	2.0	2.2
Indore	2.007	3.325	5.292	1.8	2.1	2.4
Pune	7.760	12.819	21.111	7.0	8.2	9.7
Greater Mumbai	22.107	30.568	43.039	20.0	19.5	19.8
Hyderabad	13.528	20.652	29.730	12.2	13.2	13.7
Chennai	15.273	21.434	26.236	13.8	13.7	12.1
Bengaluru	12.300	16.260	21.219	11.1	10.4	9.8
Kolkata	15.528	20.006	25.588	14.0	12.8	11.8
Total	110.635	156.873	217.147	100.0	100.0	100.0

Source: CEA, 18th EPS, Volume II.

requirement of India in 2011–2012, while they housed just 7.5% of the country's population. The report was prepared by adopting suitable growth rates, factors influencing the growth in electricity demand and also taking into consideration the transmission and distribution losses. The results of the EPS is presented in the Table 1.

2.2. Land Use/Land Cover Classification

The very first objective is land use-land cover classification. However the best classification technique to be adopted for classification was evaluated by classifying the study area using various classification techniques [15]. The Support Vector Machine Classifier was selected as the best classification technique after it

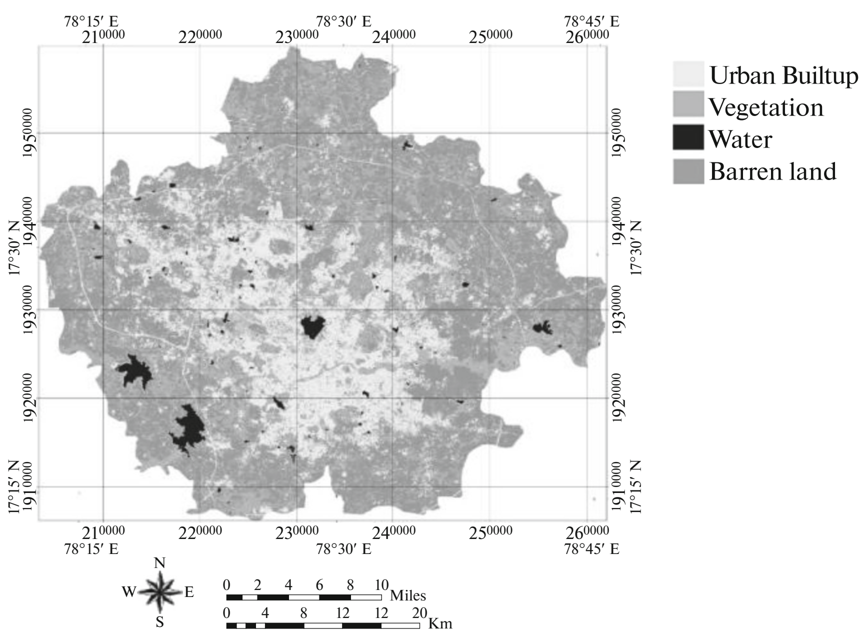

Fig. 3. Land use/land cover classified of study area using support vector machine classified.

Table 2. Land use/land cover class Statistics

Year in area and %		Land use class			
		Urban built-up	Water bodies	Vegetation	Barren land
2014	km^2	499.08	59.42	464.56	937.95
	%	25.45	3.03	23.69	47.83

gave an overall accuracy of over 96.39% and Kappa Statistic of 0.9533, both of which were higher than the other classification techniques including Maximum Likelihood Classifier, Neural Network Classifier, Parallelepiped Classifier, Minimum Distance Classifier, K-Means Clustering Classifier and ISODATA Classifier. The Remote sensing data used for the study is Landsat 8 OLI (2014). This image of 2014 was classified using supervised classification. It is observed that urban built up areas extend to 499 km^2 (in 2014) out of the total area of 1905 km^2 of Hyderabad city (Fig. 3, Table 2). Very high resolution data of 0.6 m resolution is necessary to accurately evaluate the available bright roof tops. Due to lack of availability of the same, the total urban built-up area available is assessed using Landsat 8 OLI data of 2014. The bright roof top area is estimated after applying certain coefficients as explained in 2.3.

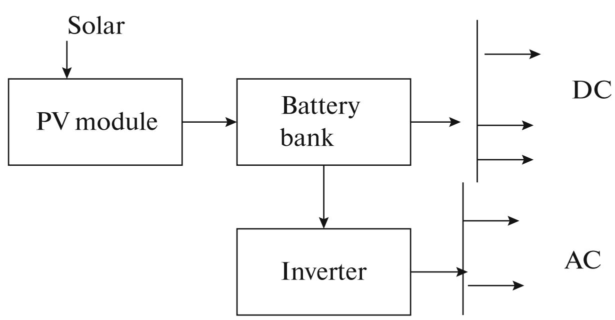

Fig. 4. Photovoltaic system flowchart.

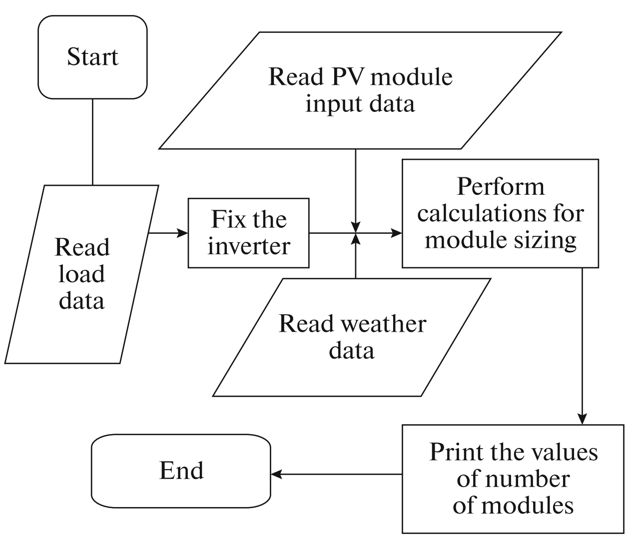

Fig. 5. PV sizing algorithm.

2.3. Roof Area Estimation

Three types of surface areas are used in this methodology: 1) built-up area (A_b), 2) roof area within a built-up area (A_r) and 3) roof area available for solar applications (A_a). The available roof area is evaluated by applying certain restrictions or coefficients representing the void fraction (C_v), the shadow coefficient (C_s), and the facility coefficient (C_f) which includes roofs that are dedicated for other uses [5] as presented in Eq. (1).

$$A_a = A_r C_s C_f = A_b C_v C_s C_f. \quad (1)$$

2.4. PV System Sizing

A PV system is construed as a source of energy which transforms solar radiation energy to electrical energy. By means of photo effect the radiation energy is transferred directly to the electrons in the PV crystals [16]. The PV system sizing evaluates the number of PV modules and space required for setting up a photovoltaic power generation unit for the given load demand of the city. The load is connected to grid and hence does not require a battery bank. However power conditioning units are required for the efficient dispatch of the power generated. A photovoltaic system as shown in Fig. 4 consists of an integrated assembly of modules and other components, designed to convert solar energy into electricity.

2.5. PV System Sizing Algorithm

The system discussed here being grid interactive requires no storage facility. Solar radiation being highly unpredictable commodity, the load demand cannot be predicted accurately and therefore sizing is an approximate calculation based on probability [18]. The algorithm for calculating the sizing requirement of a PV system for a given energy demand is shown in Fig 5. The algorithm is based on the analytical approach which takes care of the radiation profile of Hyderabad city. The simple idea behind sizing is energy balance which means

$$E_{demand} \le E_{supply} \text{ [19].}$$

Table 3. Module Inverter parameters and Radiation input

Module Parameters	
Model Number	L1270 (BHEL Make)
Maximum Power	70 W
Short circuit current (I_{sc})	4.6 A
Open circuit voltage (V_{oc})	21 V
Current at max power (I_{mp})	4.3 A
Max current rating of module (I_m)	4.4 A
Current rating of charge controller (A_r)	10
No: of sub-arrays and regulators	4458
VOLTAGE AT PEAK POWER POINT (V_M)	16.4 V
Inverter parameters	
Efficiency (E_i)	0.9
System voltage (V_{dc})	24 V
Radiation input	
T8 = 25°C – Min Temperature at site h_s = 5.12 hrs – Hours of bright sunshine G1 = 5.12 kWh/m^2 Average solar radiation	

Table 4. Results of module sizing using simulation

Output data	Hyderabad city	1 MW
No: of modules		
Series	2	2
Parallel	76113913	7143
Total No:	1.52227826×10^8	14286
No of sub arrays and regulators		
No. of inverters	47494622	
Space Requirements (Area of modules)	1.528×10^7	
	97.42 km^2	9.143×10^3 m^2
Electricity generated daily	30000000 kW h	2.815×10^3 kW h

2.6. *Sizing of PV System*

The calculations are carried out in simulation platform. Figure 5 represents the sizing algorithm used in this study and Table 3 gives the sizing results obtained from the simulation study. These results were derived from the models given in (2–7). The required number of modules is calculated based on the module input parameters. The necessary conversion coefficients are used in finding the total daily ampere hour. This compensates for the dust and derate factor of the module. The total number of hours of sunshine is derived from the mean global radiation data. The details of the module and inverter and radiation input values are tabulated in Table 3.

$$Nps = (Vdc/Vm), \quad (2)$$

$$Npp = (Pc/(W \times Nps), \quad (3)$$

$$Ahd = (Im \times hs \times 0.9 \times 0.9 \times Npp), \quad (4)$$

$$Wht = (Ahd \times Vdc \times Ei), \quad (5)$$

$$Nar = (Npp \times Isc \times 1.3/Ar), \quad (6)$$

$$\text{Area of the modules required} = 0.64 \times Nps \times Npp. \quad (7)$$

3. RESULTS AND DISCUSSION

Hyderabad cities average energy demand of 30 million units per day for the year 2014–2015 has been considered for the design of the PV system for the city. Table 4 gives the simulation results of module sizing for the total electricity requirement of Hyderabad city and also of a 1 MW solar power plant.

4. TOTAL PV REQUIREMENTS FOR HYDERABAD CITY AND 1MW POWER PLANT

The bright roof area necessary to meet the Power demand of Hyderabad city is 97.42 km^2 so as to generate 30 million units of solarelectricity. The urban built up area, based on the land-use land cover classification of 2014 is 499 km^2. The roof top area available (1) for solar PV application is 62.375 km^2 which can meet upto 64% of the power requirement of Hyderabad city. Radiation input of 5.12 kW h/m^2 is the average of readings observed from January to December 2014. The sizing was done using simulation platform and the results obtained are tabulated in Table 4. The total space requirement for a 1MW plant is found to be 9143 m^2 and to meet the total energy demand of Hyderabad, 1.52227826×10^8 modules are needed which would require a space of about 97.42 km^2. The module requirements of a 1 MW power plant can generate energy of 2815 units. This can be scaled up to higher MW as required.

5. CONCLUSIONS

Solar electricity is a plausible and suitable solution for a city grappling with power crisis. The available bright roof area is likely to suffice meeting 64% of the total power requirement of Hyderabad city. Data for this study was obtained from easily available open source geospatial data. Much higher accuracy can be achieved if technically advanced datasets of LIDAR or photogrammetry are used. This study would not have been possible without the help of Geospatial data and it has proved to be an invaluable tool in studies of present scale and also at macro level.

REFERENCES

1. Power consumption spirals, *The Hindu,* 12.03.2015.
2. Kabir, H.Md., Endlicher, W., and Jagermeyr, J., Calculation of bright roof- tops for solar PV applications in Dhaka megacity, Bangladesh, *Renew. Energy,* 2010, vol. 35, pp. 1760–1764.
3. Avezov, R.R., Akhatov, J.S., and Avezova, N.R., A review on photovoltaic-thermal (PV-T) air and water collectors, *Appl. Solar Energy,* 2011, vol. 47, no. 3, pp. 169–183.
4. Telangana Power Policy 2015. http://ww.tssouthern-power.com. Accessed 27.05.2015.
5. Izquierdo, S., Rodrigues, M., and Fueyo, N., A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations, *Solar Energy,* 2008, vol. 82, pp. 929–939.
6. Castro, M., Delgado, A., Argul, F., et al., Grid-connected PV buildings: analysis of future scenarios with an example of southern Spain, *Solar Energy,* 2005, vol. 79, pp. 86–95.
7. Ghisi, E., Montibeller, A., and Schmidt, R.W., Potential for potable water savings by using rainwater: an analysis over 62 cities in southern Brazil, *Build. Environ.,* 2006, vol. 41, pp. 204–210.
8. Kaplani, E. and Kaplanis, S., A stochastic simulation model for reliable PV system sizing providing for solar radiation fluctuations, *Appl. Energy,* 2012, vol. 97, pp. 970–981.
9. Vinter, G. and Slonim, M., Introducing very large scale PV systems in Israel, *Appl. Solar Energy,* 2009, vol. 45, no. 4, pp. 224–232.
10. Fragaki, A. and Markvart, T., Stand-alone PV system design: results using a new sizing approach, *Renew. Energy,* 2008, vol. 33, pp. 162–167.
11. Uzunoglu, M., Onar, O.C., and Alam, M.S., Modelling, control and simulation of a PV/FC/UC based hybrid power generation system for standalone applications, *Renew. Energy,* 2009, vol. 34, pp. 509–520.
12. Dufo-Lopez, R., Jose, L., Agustin, B., et al., Multi objective optimization minimizing cost and life cycle emissions of stand-alone PV-wind-diesel systems with battery storage, *Appl. Energy,* 2011, vol. 88, pp. 4033–4041.
13. Kaushika, N.D, Gautam, N. K., and Kaushik, K., Simulation model for sizing of stand alone solar PV system with inter connected array, *Solar Energy Mater. Solar Cells,* 2005, vol. 85, pp. 499–511.
14. APSPDCL. http://www.apcentralpower.com. Accessed 18.12.2013.
15. Census, 2011. http://www.census2011.co.in. Accessed 20.02.2014.
16. Mega-cities power consumption to go up 7% annually. http://www.projectsmonitor.com/insight/mega-cities-power-consumption-to-go-up-7-annually/. Accessed 09.04.2016.
17. Franco, S. and Mandla, V.R., Evaluation of various classification techniques for land use, land cover with special reference to urban mapping, *Int. J. Earth Sci. Eng.,* 2012, vol. 5, no. 3, pp. 494–500.
18. Skunpong, R. and Plangklang, B., A practical method for quickly PV sizing, *Proc. Eng.,* 2011, vol. 8, pp. 120–127.
19. Sharma, V.K., Colangelo, A., and Spagna, G., Photovoltaic technology: basic concepts, sizing of a stand-alone photovoltaic system for domestic applications and preliminary economic analysis, *Energy Convers. Manag.,* 1995, vol. 36, no. 3, pp. 161–174.