TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 11, November 2014, pp. 7681 ~ 7689
DOI: 10.11591/telkomnika.v12i11.6677

A New Approach towards Ideal Location Selection for PV Power Plant in India

Suprava Chakraborty*, Pradip Kumar Sadhu, Nitai Pal
Department of Electrical Engineering, Indian School of Mines,
Dhanbad, Jharkhand, India-826004, Tel.:+91-326-223-5478; fax: +91-326-229-6563
*Corresponding author, e-mail: suprava1008@gmail

Abstract

India is the seventh largest country in the world, blessed with adequate solar radiation, therefore to setting up a Photovoltaic power plant is a lucrative option. In actual field conditions the performance of the PV modules vary significantly from its Standard Test Condition (STC) due to large change in environmental conditions. It is very important to study the exact meteorological parameters for different locations in India before installation of a Photovoltaic power plant. In this paper, the long-term meteorological parameters for the seventy considered locations in India from National Aeronautics and Space Administration (NASA) renewable energy resource website (Surface Meteorology and Solar Energy) are collected and analyzed in order to select an ideal location for installation of PV power plant. This paper helps the investors, Ministry of New and Renewable Energy (MNRE), Electricity Authority and Planning Commission to select proper locations for installation of PV power plant.

Keywords: *meteorological parameter, photovoltaic power, STC, solar radiation*

1. Introduction

The Technological dependency of the modern world on fossil fuels and the ways in which these fuels have gradually degraded the earth's environment is pretty alarming [1, 2]. In this present generation, climate is receiving extraordinary awareness because, human activity on earth for the last hundred years is considerably diverse which resulted rapid changes in the environmental conditions [3].

Energy demand of India is increasing day by day to supplement its ambitious economic growth. Affordable and sustainable energy is one of the primary requirements for economic growth, improving the quality of life and increasing the opportunities of development [4]. Currently, India suffers from a major shortage of electrical power generation [5]. Indian electricity sector had an installed capacity of 245.39 GW up to end of April, 2014, [6, 7] i.e. world's 4th largest [8]. India generated 855 TWh of electricity during 2011-12, expected demand by 2016-17 will be 1392 TWh and by 2021-22 it will be 1915 TWh [9]. Technology is a key factor of future energy policy for the country. Suitable technological choices are vital for both supply and demand sides.

To meet this huge energy demand and to provide a clean environment for the future generation renewable energy should be given preference in India [10]. Among the various renewable energy resources, India is enriched with ample potential of solar energy generation due to its geographical location near Tropic of Cancer [11]. In India nearly 58% areas are receiving annual average Global insolation more than 5 kWh/m^2/day [12]. Considering the long run effect of pollutants from fossil fuels on human health and environment [13], electricity generation from PV module is an alternative cost effective solution [11].

A lot of work has been done on analysis of the environmental factors that influence the performance of PV module [14-18]. The performance of PV module is mainly influenced by solar insolation and ambient temperature [19, 20]. On the other hand, the performance of PV module is indirectly influenced by other several parameters such as solar radiation incident angle, sunshine duration, humidity, dust [21] etc. It is important to study all aforesaid meteorological parameters to know the actual performance of PV modules in field condition [22].

In SWERA project, Martins et al. prepared solar energy resource map of Brazil utilising satellite irradiation model and NREL irradiation data [23]. The potential of harnessing solar

Received August 19, 2014; Revised September 21, 2014; Accepted October 2, 2014

radiation in different regions of Iran was studied by Besarati et al. and solar radiation maps were also generated [24]. Yeo and Yee used energy geographical information system (E-GIS) database (DB) and an artificial neural network (ANN) to determine location potential model for urban energy supply plants [22]. Polo et al. estimated daily global horizontal and direct normal irradiation for six locations in India covering the years from 2000 till 2007 [25]. For viability analysis of PV power plants in Egypt long-term meteorological parameters for 29 considered sites were analyzed by Shimy [26]. Four meteorological parameters are analyzed in viability study of Solar PV plants in Egypt but insolation clearness index and solar insolation in equator pointed surface that is tilted at latitude angle were not considered in this paper [26]. Sharma and Tiwari evaluated the technical performance of 2.32 kW_p stand-alone PV array systems for climatic condition of New Delhi considering insolation, temperature and sunshine hours [247 Other meteorological parameters except solar radiation were not analyzed in [22, 23, 24, 26] and only six locations of India were considered in [25]. Precise information on the performance of different Photovoltaic technologies in actual field conditions is essential for right product selection and accurate estimation of their electricity production [28, 29].

2. Research Method

NASA Surface Meteorology and Solar Energy database [30] is the key source of solar energy and meteorological data used in this paper. The global availability of these data on a 1°×1° grid with the same temporal, spatial resolution and same definition across all geographical regions makes this method globally applicable. The data is generated using the NASA Goddard Earth Observing System - Version 4 (GEOS-4). The solar energy data is generated using the Pinker/Laszlo shortwave algorithm. Cloud data is taken from the International Satellite Cloud Climatology Project DX dataset (ISCCP) [30].

Figure 1. Map of India Locating the Selected Sites

The mainland of India extends between 8°4' to 37°6' (N) North Latitude and 68°7' to 97°25' (E) East Longitudes. India is divided into 6 zones i.e. Northern, Eastern, North-Eastern, Southern, Western and Middle zone. Total 70 locations are selected from these zones. Insolation on horizontal surface, insolation incident on an equator-pointed surface that is tilted at latitude angle, insolation clearness index, daylight hours, air temperature and relative humidity data are collected for the analysis. The long-term values and the long-term monthly averaged values of the above mentioned parameters are obtained using the long-term site averages and monthly mean values for all the considered sites. Insolation on horizontal surface is the amount of electromagnetic energy (solar radiation) incident on the surface of the earth and expressed in kWh/m^2/day. Insolation clearness index is a dimensionless parameter and is defined as fraction of insolation at the top of the atmosphere which reaches the surface of the earth. Insolation on tilted surfaces is calculated from the monthly average insolation on a horizontal surface and expressed in kWh/m^2/day. In this paper the tilt angle of the surface is equal to the latitude angle of the considered location. Relative humidity is the ratio of actual partial pressure of water vapour to the partial pressure at saturation, expressed in percent. Day light hour is the time between sunrise and sunset.

The Tropic of Cancer 23°30' N divides India almost into two halves named as Upper and Lower India. For graphical representation of the above mentioned meteorological parameters, 35 locations in each part of India are considered. Most of the selected sites in India are shown in Figure 1. Analysis of meteorological parameters to select suitable site for installation of PV power plant in India are presented in consequent part of this paper.

3. Results and Analysis

In The long-term averaged insolation incident on a horizontal surface (MWh/m^2/year) and insolation incident on an equator-pointed surface that is tilted at latitude angle for each of the 35 locations in Upper India and 35 locations in lower India are shown in Figure 2-5, respectively.

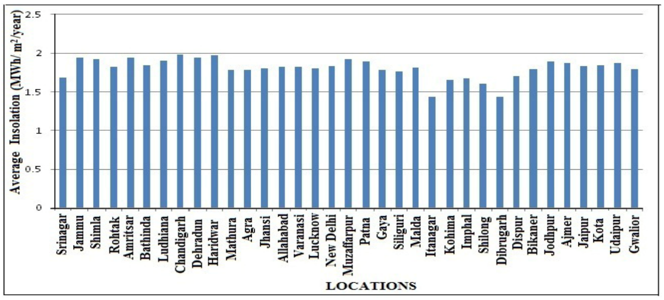

Figure 2. The Long-term Averaged Insolation Incident on a Horizontal Surface over Various Sites in Upper India

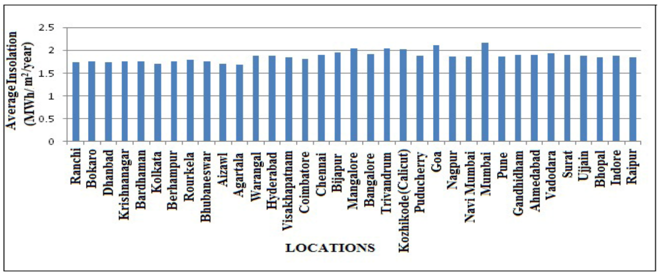

Figure 3. The Long-term Averaged Insolation Incident on a Horizontal Surface over Various Sites in Lower India

Based on Figure 2 and 3, the global solar radiation is geographically dependent such that it varies from a minimum value of 1.43 MWh/m^2/year at Dibrugarh (Assam) to a maximum value of 2.16 MWh/m^2/year at Mumbai (Maharashtra). It is clear from Figure 2 & 3, the amount of solar radiation is higher in west and south part and lower in north – eastern part of India with an average global solar radiation of 5.03kW/m^2/day over the entire region (only 70 locations are considered). India can be considered as one of the best regions for solar energy related projects. In Mumbai, Jammu and Haridwar average daily global insolation varies respectively from 5.09-7.37kWh/m^2/day, 3.15-7.47kWh/m^2/day and 3.64-7.59kWh/m^2/day. Among these 70 locations maximum and minimum annual average insolation on horizontal surface is found in Mumbai and Itanagar as 5.93kWh/m^2/day and 3.92kWh/m^2/day respectively. The seasonal pattern of the solar radiations matches with the electrical load pattern in India.

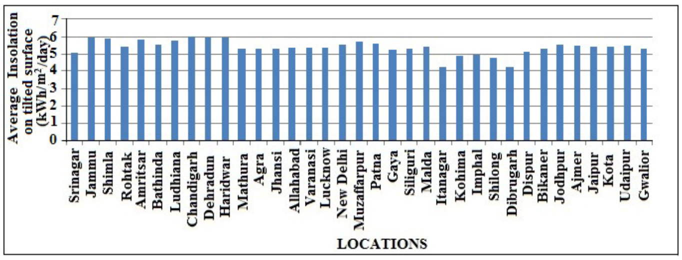

Figure 4. Monthly Averaged Insolation Incident on an Equator-Pointed Latitude Angle Tilted Surface over Various Sites in Upper India

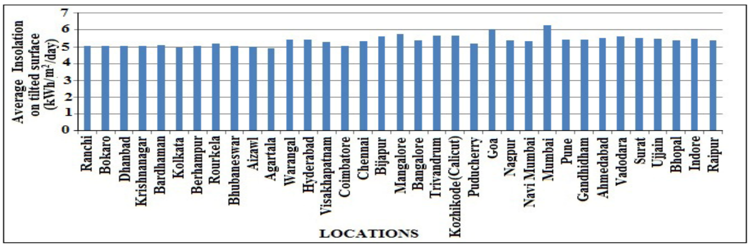

Figure 5. Monthly Averaged Insolation Incident on an Equator-Pointed Latitude Angle Tilted Surface over Various Sites in Lower India

The long-term daily average insolation incident on an equator-pointed surface that is tilted at latitude angle (kWh/m^2/day) over the considered 35 sites in Upper India, 35 sites in lower India are shown in Figure 4 and 5. Maximum annual averaged titled insolation is 6.27kWh/m^2/day in Mumbai, where as minimum is 4.21kWh/m^2/day in Itanagar. Maximum value of insolation incident on equator facing surface that is tilted at latitude angle is found 7.46kWh/m^2/day in the month of March at Mumbai and minimum 3.34kWh/m^2/day in the month of August at Navi Mumbai.

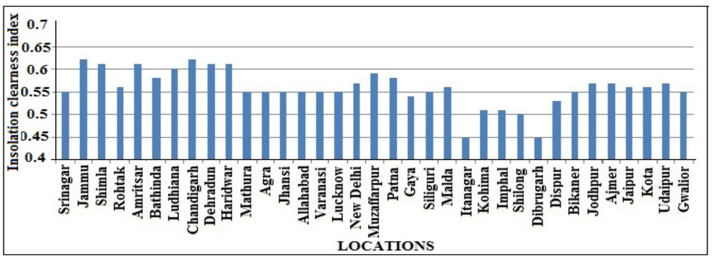

Figure 6. Monthly Averaged Insolation Clearness Index (0 to 1.0) over Various Sites in Upper India

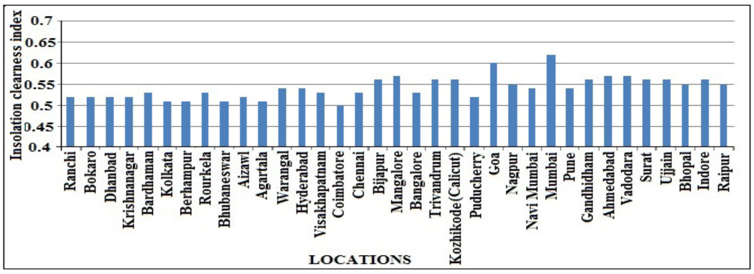

Figure 7.Monthly Averaged Insolation Clearness Index (0 to 1.0) over Various Sites in Lower India

Insolation clearness index is defined as the fraction of insolation at the top of the atmosphere which reaches the surface of the earth. It is a dimensionless parameter. The long-term daily average insolation clearness index in selected sites of upper India and lower India are shown in Figure 6 and 7 respectively. Higher clearness index indicates good amount of solar radiation reaches to the atmosphere of the earth. Annual average insolation clearness index is maximum 0.62 at Mumbai, Jammu and Chandigarh and minimum 0.45 at Itanagar and Dibrugarh of Assam. Considering monthly insolation clearness index for 70 locations maximum 0.73 is found in the month of November at Shimla and minimum (0.32) is in Shilong during the month of July. It indicates during the month of November at Shimla most of the radiation from the outer atmosphere reaches to the earth.

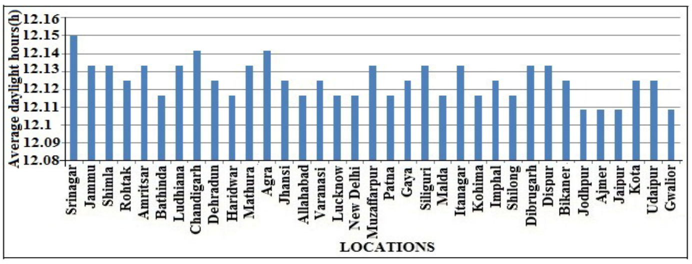

Figure 8. Monthly Averaged Daylight hours (hours) over Various Sites in Upper India

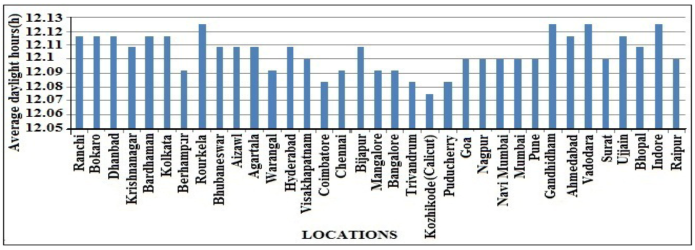

Figure 9. Monthly Averaged Daylight Hours (hours) over Various Sites in lower India

Time between sunrise and sunset is considered as daylight hours. Daylight hours over the considered 35 sites in each half of India are shown in Figure 8 and 9 respectively.

It is clear from Figure 8 and 9 that the daylight hours are insignificantly dependent on the geographical locations and at least 10 hrs of daylight hours exist over India. From seasonal point of view shown in Figure 13, the daylight hours is longer in summer months (maximum in June) and shorter in winter months (minimum in December) for all the considered sites. Maximum daylight hours of 14.4hrs occur at June and a minimum of 9.9hrs occurs at December. But unexpectedly both the maximum and minimum daylight hours among 70 locations is observed in Srinagar during different months of the year. Annual average value of daylight hours is maximum 12.15hrs in Srinagar and minimum 12.07hrs in Kozhikode (Calicut) of Kerala.

In order to check the environmental settlement in India with the essential standard operating conditions for PV modules a study of the long-term monthly averaged air temperature and the long-term monthly averaged relative humidity is carried out with relevant data obtained from NASA renewable energy resource website (Surface Meteorology and Solar Energy) [30]. The long-term annual averaged air temperature at 10 m above the surface of the earth (°C) and relative humidity (%) are shown in Figure 10-13, respectively.

Figure 10. The Long-term Monthly Averaged Air Temperature at 10 m above the Surface of the Earth (°C) for Sites in Upper India

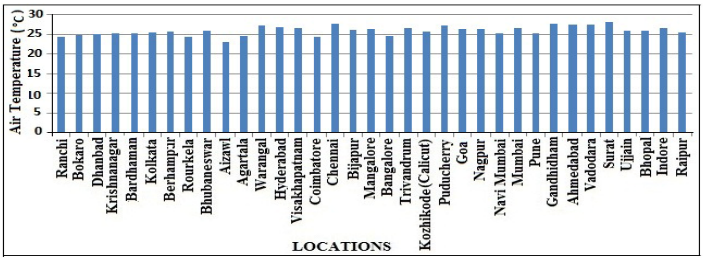

Figure 11. The Long-term Monthly Averaged Air Temperature at 10 m above the Surface of the Earth (°C) for Sites in lower India

Temperature is an important parameter that affects the output of PV modules. The average air temperature over India increases from north to south. Average air temperature over the entire region (only 70 locations are considered) is 23.77°C which is within the range of Standard operating condition of PV modules. A maximum air temperature of 34.4°C occurs in May at Nagpur and a minimum of -6.74°C occurs in December at Srinagar among 70 locations. Annual average value of air temperature at 10m above the surface is maximum 28.2°C in Surat and minimum 5.39°C in Srinagar.

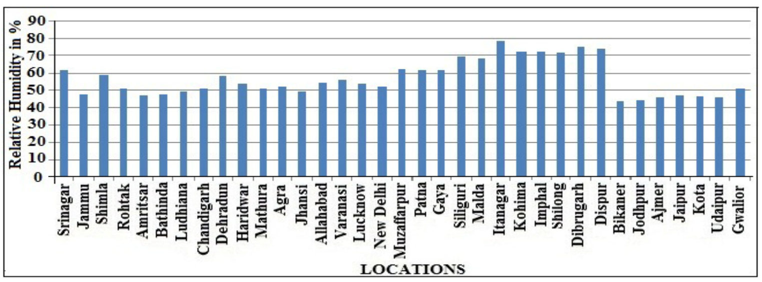

Figure 12. The Long-term Monthly Averaged Relative Humidity (%) for Sites in Upper India

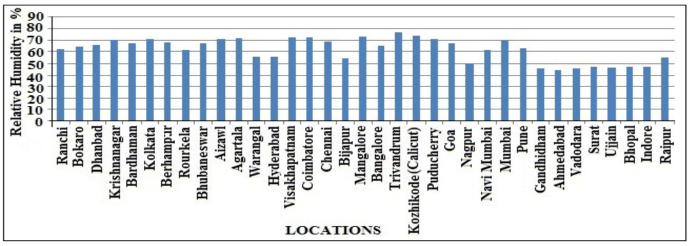

Figure 13. The Long-term Monthly Averaged Relative Humidity (%) for Sites in Lower India

Humidity is a parameter that causes degradation of PV module. It is clear from Figure 12 and 13, the long-term humidity for different sites in India matches with the Standard operating condition range of PV modules. Maximum annual average relative humidity among 70 locations is 78.3% occurs in Itanagar and minimum is 43.5% in Bikaner. The relative humidity is higher in monsoon with average value of 79.9% in August than in spring with average value of 43.42% in March. A maximum relative humidity of 88.1% occurs during July in Siliguri and a minimum of 22.4% occurs during April in Bhopal among 70 locations. Relative humidity is higher in North-eastern and southern part of India than other locations.

Considered ideal range of different meteorological parameters for PV power plant installation concluded from various literatures, i.e. Global Horizontal Insolation (GHI), Tilted Insolation (TI), Insolation clearness index (K_t), Daylight hours (S), air temperature (T) greater than or equal to 1.8 MWh/m^2/Year, 5kWh/m^2/Day, 0.55, 12h, 25°C respectively and Relative Humidity (RH) is between 44% to 52%. Suggested locations for PV power plant installation depending on considered ideal range of different meteorological parameter are tabulated in Table 1.

Table 1. Suggested Locations for PV Power Plant Installation Depending on Different Meteorological Parameters

Location	GHI[a]≥1.8	TI[b]≥5	K_t[c]≥0.55	S[d]≥12	T[e]≤25	44≤RH[f]≥52
Jammu, Rohtak, Amritsar, Bathinda, Ludhiana, Chandigarh, Mathura, Jodhpur, Ajmer, Jaipur.	√	√	√	√	√	√
Shimla, Dehradun, Haridwar, Agra, New Delhi, Muzaffarpur, Bikaner, Patna, Malda.	√	√	√	√	√	×
Kota, Udaipur, Ujjain, Bhopal, Gwalior, Indore, Gandhidham, Ahmedabad, Vadodara, Surat, Nagpur, Jhansi.	√	√	√	√	×	√
Mumbai, Goa, Trivandrum, Kozhikode (Calicut), Bijapur, Mangalore, Allahabad, Varanasi, Raipur, Kanpur.	√	√	√	√	×	×
Gaya, Rourkela, Coimbatore, Bangalore.	√	√	×	√	√	×
Warangal, Hyderabad, Visakhapatnam, Chennai, Puducherry, Navi Mumbai, Pune, Bardhaman.	√	√	×	√	×	×
Srinagar, Siliguri.	×	√	√	√	√	×
Ranchi, Bokaro, Dhanbad, Aizawl, Guwahati.	×	√	×	√	√	×
Krishnanagar, Berhampur, Bhubaneswar.	×	√	×	√	×	×
Itanagar, Kohima, Imphal, Agartala, Shillong, Dibrugarh.	×	×	×	√	√	×
Kolkata.	×	×	×	√	×	×

[a]GHI: Averaged insolation on horizontal surface (MWh/m^2/Year).
[b]TI: Annual averaged insolation on equator pointed surface i.e. tilted at latitude angle (KWh/m^2/Day).
[c]K_t: Annual averaged insolation clearness index.
[d]S: Annual averaged daylight hours(h).
[e]T: Annual averaged air temperature (°C).
[f]RH: Annual averaged relative humidity (%)

4. Conclusion

In this paper the long-term meteorological parameters from NASA renewable energy resource website (Surface Meteorology and Solar Energy) for 70 considered locations in India are analyzed. The data taken from NASA website is a monthly average of previous 22 years. Study shows that India is a country with diverse environmental conditions and has sufficient amount of solar radiation all over the year. Before setting up a PV power plant in a country like India only analysis of GHI or air temperature of that location are not sufficient but other meteorological parameters are equally important to analyse before selecting appropriate location. If the other important parameters are not within the ideal range then we can say that area is not ideally suited for installation of large PV power plant. The study of the collected meteorological parameters ensures the compatibility of India's meteorological conditions with the safety operating condition range of the PV-modules. This analysis help technologist to select appropriate PV technology environmentally best suited for a particular location.

This paper is an effective one for PV power plant installer along with different agencies like Ministry of New and Renewable Energy, Electricity Authority and Planning Commission of India to select appropriate location for installation of PV power plant considering various meteorological parameters.

References

[1] Steven S. Fossil fuel addiction and the implications for climate change policy. Global Environ Change 2013; 23: 598–608.
[2] Hook M, Tang X. Depletion of fossil fuels and anthropogenic climate change-A review. Energ Policy 2013; 52: 797–809.
[3] Holtsmark B, Maestad O. Emission trading under the Kyoto Protocol-effects on fossil fuel markets under alternative regimes. Energ Policy. 2002; 30: 207–18.
[4] Bose RK, Shukla M. Elasticities of electricity demand in India. Energ Policy 1999; 27: 137-46.
[5] Bellarmine GT, Arokiaswamy NSS. Energy Management techniques to meet power shortage problems in India. Energ Convers Manage 1996; 37(3): 319-28.
[6] Monthly all India generation capacity report. Central Electricity Authority, Ministry of Power, Government of India. < http://www.cea.nic.in/installed_capacity.html>. (Accessed May 2014)
[7] Executive summary of month of February 2014. Central Electricity Authority, Ministry of Power, Government of India. <http://www.cea.nic.in/reports/monthly/executive_rep/feb14.pdf>.(Accessed March 2014)
[8] International Energy Statistics. <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7>. (Accessed February 2014)
[9] Get enlightened about electricity - India (1 MU = 1 Million Units in India = 1 GWhr), The Financial Express. 2004.
[10] Mukhopadhyay K, Forssell O. An empirical investigation of air pollution from fossil fuel combustion and its impact on health in India during 1973–1974 to 1996–1997. Ecol Econ 2005; 55: 235 – 50.
[11] Sharma NK, Tiwari PK, Sood YR. Solar energy in India: Strategies, policies, perspectives and future potential. *Renew Sust Energ Rev.* 2012; 16:933– 41.
[12] Ramachandra TV, Jain R, Krishnadas G. Hotspots of solar potential in India. *Renew Sust Energ Rev.* 2011; 15: 3178– 86.
[13] Singh SK. Future mobility in India: Implications for energy demand and CO_2emission. Transport Policy. 2006; 13: 398–412.
[14] Kerr MJ, Cuevas A. Generalized analysis of the illumination intensity vs. open-circuit voltage of PV modules. *Sol Energ.* 2003; 76: 263–7.
[15] Radziemska E, Klugmann E. Thermally-affected parameters of the current–voltage characteristics of silicon photocell. *Energ Convers Manage.* 2002; 43: 1889–900.
[16] Van Dyk EE, Meyer EL, Leitch AWR, Scott BJ. Temperature-dependent of performance of crystalline silicon photovoltaic modules. *S Afr J Sci.* 2000; 96:198–200.
[17] Nishioka K, Hatayama T, Uraoka Y, Fuyuki T, Hagihara R, Watanabe M. Field-test analysis of PV-system-output characteristics focusing on module temperature. *Sol Energ Mat Sol C*. 2003; 75: 665–71.
[18] Sharma C., Jain A, Simulink Based Multi Variable Solar Panel Modeling, TELKOMNIKA Indonesian Journal of Electrical Engineering , Vol. 12, No. 8, August 2014, pp. 5784 ~ 5792 ,DOI: 10.11591/telkomnika.v12i8.6071.
[19] Hassane Ben Slimane, Ben Moussa Dennai, and Helmaoui Abderrachid, Theoretical Study of Multiple Solar Cells System as a Function of Temperature. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2014; 12(7): 4928-4933 ,DOI: 10.11591/telkomnika.v12i7.5363.

[20] Ehsan Hosseini, Modeling and Simulation of Silicon Solar Cell in MATLAB/SIMULINK for Optimization. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2014; 12(8): 6047 ~ 6054, DOI: 10.11591/telkomnika.v12i8.5294.
[21] Yerli B, Kaymak MK, Izgi E, Oztopal A, Şahin AD. Effect of derating factors on photovoltaics under climatic conditions of Istanbul. *World Acad Sci Eng Technol*. 2010; 44:1400-4.
[22] Yeo IA, Yee JJ. A proposal for a site location planning model of environmentally friendly urban energy supply plants using an environment and energy geographical information system (E-GIS) database (DB) and an artificial neural network (ANN). *Appl Energ.* 2014; 119: 99–117.
[23] Martins FR, Pereira EB, Abreu SL. Satellite-derived solar resource maps for Brazil under SWERA project. *Sol Energ*. 2007; 81(4): 517–28.
[24] Besarati SM, Padilla RV, Goswami YD, Stefanakos E. The potential of harnessing solar radiation in Iran: Generating solar maps and viability study of PV power plants. *Renew Energ.* 2013; 53:193-99.
[25] Polo J, Zarzalejo LF, Cony M, Navarro AA, Marchante R, Martın L, Romero M. Solar radiation estimations over India using Meteosat satellite images*. Sol Energ*. 2011; 85: 2395–406.
[26] Shimy MEL. Viability analysis of PV power plants in Egypt. *Renew Energ*. 2009; 34: 2187–96.
[27] Sharma R, Tiwari GN. Technical performance evaluation of stand-alone photovoltaic array for outdoor field conditions of New Delhi. *Appl Energ*. 2012; 92: 644–52.
[28] Durisch W, Tille D, Worz A, Waltraud P. Characterisation of photovoltaic generators. *Appl Energ.* 2000; 65:273–84.
[29] Sasitharanuwat A, Wattanapong R, Nipon K, Suchart Y. Performance evaluation of a 10 kW_p PV power system prototype for isolated building in Thailand. *Renew Energ*. 2007; 32:1288–300.
[30] Surface meteorology and solar energy. NASA renewable energy resource website. < http://eosweb.larc.nasa.gov/sse/>. (Accessed January 2014).