Renewable and Sustainable Energy Reviews 52 (2015) 357–365

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Performance analyzes of different photovoltaic module technologies under İzmit, Kocaeli climatic conditions

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ARTICLE INFO

Article history:
Received 22 January 2015
Received in revised form
15 May 2015
Accepted 25 July 2015
Available online 14 August 2015

Keywords:
PV module
Energy performance
Performance ratio
Means array efficiency
Capacity factor
Solar energy potential

ABSTRACT

This paper presents an energy performance analysis of three different photovoltaic (PV) modules technologies under İzmit, Kocaeli weather conditions in Northwest of Turkey. Some comparative analyzes were conducted for showing solar energy potential of İzmit, Kocaeli. For this purpose, by using crystalline (c-Si), multi crystalline (mc-Si) and cadmium–telluride (Cd–Te) modules, three on-grid photovoltaic power systems (PPS) were installed on the rooftop of the Engineering Faculty at Kocaeli University. These PPSs were monitored from October, 2013 to December, 2014. In order to determine the energy performances of PV modules and PPSs, normalized energy of systems, performance ratios (PRs), mean array efficiencies (MAEs) and capacity factors (CFs) were calculated. The results show that due to the low dependency on weather changes, MAE of Cd–Te arrays result in higher value than that of the other arrays. Changes in PRs of c-Si and mc-Si arrays are lower than Cd–Te arrays within the measurement period and mean values of PRs are 83.8%, 82.05% and 89.76% for mc-Si, c-Si and Cd–Te arrays, respectively. Since Cd–Te array has the highest CF during all months, Cd–Te array can be accepted as more reliable array under İzmit climatic condition. On the other hand, one of the outcomes of this study is to reveal the solar energy potential of İzmit by on-site measurements. So, it is shown that contrary to measurement taken between 1985 and 2006 from 156 stations by General Directorate of Renewable Energy (GDRE) and Turkish State Meteorological Service (DMI), İzmit has more solar energy potential by rate of 23.79%.

Contents

1. Introduction

PV module technologies have shown great improvements in recent years [1,2]. With the significant development of material technology, power conversion efficiency of PV modules increases

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http://dx.doi.org/10.1016/j.rser.2015.07.108
1364-0321/

each passing year. According to the study of titled as the solar cell efficiency tables (Version 45) [3], the highest efficiency of mc-Si, c-Si and Cd–Te modules are 18.5%, 22.9% and 17.5% for National Renewable Energy Laboratory (NREL), Sandia and FhG-ISE, respectively [3]. These efficiencies are obtained under laboratory conditions. On the other hand, commercially efficiencies of this type of modules decrease to about 10–15%. Moreover, since manufacturers of PV modules give the efficiency value in their datasheets under standard test conditions (STC: 1000 W/m^2, 25 °C and AM:1.5), it is not generally known how PV modules perform under daily weather conditions. For this purpose, there are many regional based studies conducted in the World. Most of these studies focus on the determination of energy performances of different PV module technologies under certain period based on weather conditions such as temperature, plane of array (POA) irradiation, general climatic condition, degradation, soiling and impact of spectral irradiance distribution [4–33].

Previously published studies show that energy performance of PV modules depends on the type of materials used in production process, which determines type of PV modules, amount of temperature coefficient, solar irradiance etc. [4–20]. According to the study conducted by Simmons et al., performance of a-Si module was monitored for a year and it was shown that early performance degradation occurs in case of a-Si usage in PPS [4]. Akhmad et al. studied the performance comparison of a-Si and pc-Si modules by using data obtained in two years. It was indicated that a-Si modules were suitable for tropical climate [5]. Seasonal performances of a-Si and multi-junction modules were investigated for two locations [6]. It was shown that significant variations in the efficiency of a-Si module exist. On the other hand, multi-junction module is influenced by spectral effects. In 2004, Carr and Pryor investigated five different types of PV modules for more than a year and they reviewed that thin film modules perform better in summer months because of the low temperature coefficient [7]. In 2014, Cañete conducted similar study by using different PV modules. It was shown that efficiency of PV modules under STC depends on spectral distribution of incident irradiance and this influence is greater in thin film modules, especially in the a-Si module [8]. NREL performed to analyze the PV module performances for three locations in USA. In this context, different types of PV modules were used. It was presented that considerable variation in energy production because of both the site to site differences in reference yield and the PV module characteristics [9]. On the other hand, some of these studies aimed to show temperature effect on energy performance of PV modules. By aiming to reveal this effect, Makrides et al. investigated the temperature effect on energy performance of m-Si (c-Si) and mc-Si modules for four years by using manufacturer coefficients and their outdoor technique. It was shown that thermal annealing is a significant factor in the seasonal behavior of a-Si module technologies [10]. A similar study was conducted in Muğla, Turkey. Eke et al. studied the energy performance of c-Si modules under Muğla climatic conditions [11]. Spectral distribution of solar irradiance is another topic that was addressed in some studies [12–14]. In this context, Minemoto et al. researched the impact of spectral irradiance distribution and temperature on the outdoor performance of a-Si modules. It was shown that energy performance of a-Si modules mainly depends on spectral distribution [12]. In another study, Simon et al. revealed the comparison of spectral response for crystalline modules with outdoor measurements in sub-Sahara, South Africa. It is shown that spectral response of crystalline modules changes by season. Also, changes in spectrum greatly affect the performance of a-Si. However, HIT modules are not sensitive to this effect [13].

Jonathan et al. reviewed the performance of residential PV systems in France and Belgium [17,18]. In these studies, total generated energy, PR and energy performance index of all systems and the key parameters that affect the system performance are questioned. According to the data obtained from 6898 PV systems, mean values of PRs and performance indexes (PIs) are 76% and 85%, respectively in France. On the other hand, same analysis in [17] shows that mean values of PRs and PIs are 78% and 85%, respectively. In [19], two on-grid PV systems equipped with c-Si silicon wafer surrounded by ultra thin a-Si layers and classical c-Si module were investigated under the same location in Italy. It was found that the yearlong calculated PR values are 89.1% and 82.7% for c-Si surrounded by ultra thin a-Si layer and c-Si wafer, respectively. A similar study was conducted in Germany by using 100 PV systems and it was searched that whether PR may be 90% or not. It was shown that for the data obtained in 2010, PR changes from 70% to 90%. Median value of PR is 84%. Moreover, systems using highly efficient components and designed appropriately showed very close to 90% [21]. It has been found that energy performance of different PV module technologies changes by environmental and climatic conditions, disturbance effects such as shading and soiling and location which have been addressed in many studies [21–26]. Since performances of PV modules is affected by these factors, requirement of some analyzes becomes mandatory in order to foresee amount of generated energy within certain period. Energy performance analysis of PV modules is important for achieving high capacity factor in a power system. With the help of this analysis, appropriate module can be chosen for certain region.

The main purpose of this paper is to compare the energy performance for three selected PV module technologies under İzmit, Kocaeli climatic conditions by using some performance evaluation metrics proposed by IEC 61724 and capacity factor. In this context, three on-grid PPSs were installed by using mc-Si, c-Si and Cd–Te modules and these systems were monitored from October, 2013 to December, 2014. Monitored parameters are briefly voltages and currents of PV side and output of the inverter, solar irradiance, temperature etc. Since October, 2013, values of these parameters have been saved in ms-excel file by averaging every five minutes. By making basic assumptions during data filtering process, some of data are eliminated. Remains of them are processed in order to achieve better results. Another aim of this study is to estimate real solar energy potential of İzmit, Kocaeli by using daily averaged solar irradiation data and sunshine duration within monitored period. Moreover, the outdoor measurements and data of GDRE and DMI obtained between 1985 and 2006 from 156 stations are compared and monthly differences between the outdoor measurements and data of GDRE and DMI are emphasized.

This paper organizes as follows. The second part of this study will consider definitions of performance evaluations metrics and their mathematical formulations. For this purpose, PR, MAE, CF and some auxiliary indexes are explained. Solar energy potential of İzmit is presented by using daily total solar irradiation, sunshine duration in accordance with outdoor measurements. Furthermore, these data are compared with data of GDRE and DMI in the third section. Then, main specifications of installed PPSs are also given in Section 3. Monthly and annually analyzes results of normalized energy, PRs, MAEs and CFs are presented. Then, some comparative results are described in Section 4. Finally, an overall summary of the results are pointed in the last section.

2. Performance evaluation metrics

Power conversion efficiency value of PV modules is very low compared with the other components in PPSs. Since their available power depends on environmental conditions such as solar irradiance,