Energy Conversion and Management 80 (2014) 97–102

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Performance analysis and comparison of two silicon material based photovoltaic technologies under actual climatic conditions in Western India

Brijesh Tripathi [a,b], Pankaj Yadav [a], Siddharth Rathod [a], Manoj Kumar [b,*]

[a] School of Solar Energy, Pandit Deendayal Petroleum University, Gandhinagar 382007, India
[b] School of Technology, Pandit Deendayal Petroleum University, Gandhinagar 382007, India

ARTICLE INFO

Article history:
Received 12 November 2013
Accepted 11 January 2014
Available online 7 February 2014

Keywords:
Solar PV system
mc-Si solar PV module
a-Si solar PV module
Performance ratio

ABSTRACT

A study is conducted for solar PV energy generation from two grid-connected installations (mc-Si and a-Si power plants) located at the same place in Gujarat, Western India. Data-sets on electricity production were collected over entire year and compared under actual climatic conditions. The final yield of mc-Si power plant varied from a lower value of 2.79 h/d in the month of August to a maximum value of 5.14 h/d in the month of March. Final yield for amorphous silicon power plant varied from a lower value of 2.62 h/d in the month of August to a maximum value of 4.84 h/d in the month of March. The performance ratio (PR) of the mc-Si power plant ranges from 57.1 to 93.14 and for a-Si power plant, PR ranges from 53.72 to 87.64. The a-Si solar PV power plant found to have high capture losses as compared to the mc-Si solar PV power plant.

1. Introduction

In the last decade solar energy has emerged as a promising resource of green energy alternative to non-renewable energy resources. Solar energy is probably the strongest-growing electricity generation technology, demonstrating recent annual growth rates of around 23% and worldwide production of 32.34 GW in 2012 consisting of both grid-connected and off-grid remote power supplies [1]. Besides playing the noteworthy role in the future energy blend, PV generation is significantly contributing to the environmental impact of electricity supply. PV technology is one of the best ways to harvest the solar energy since PV requires very little maintenance and is capable of giving output from microwatts to megawatts. Solar energy is effectively utilized in two ways, i.e., either by using it directly for heating or cooling of air and water without using an intermediate electric circuitry (i.e. solar thermal), or by converting it into electrical energy by using solar photovoltaic (PV) modules. Direct conversion of solar radiation into electrical energy is the most suitable way of utilizing solar energy. Among the various PV technologies, Si is one of the widely used semiconductors for the fabrication of solar cell. About 80–90% of PV cells manufactured worldwide are Si wafer based solar cells [2]. An elevated demand and exponential increase in the supply of components for PV systems have led to a very significant price drop per kW installed, and economic incentives have encouraged a large number of small investors to enter the emerging PV market.

The world PV market is rapidly growing, attracting an enormous investment interest due to various lucrative schemes offered by different nations. The lucrative schemes guarantee a higher tariff as compared to the conventional sources of energy for 25 year period with a higher supplementary subsidy [3,4]. Recently, various studies related to performance enhancement, forecasting, maintenance, power conditioning and quality analysis of grid-connected photovoltaic power plant have received much attention [5–11]. Due to ever increasing demand and supply of solar PV modules it becomes very important to compare the performance of available technologies in actual climatic conditions. In this article a comparative study on the performance of amorphous silicon (a-Si) solar PV power plant and multi-crystalline silicon (mc-Si) solar PV power plant (being a part of 1 MW power plant) under hot Indian climatic conditions is presented.

2. Performance evaluation of power plant

The total daily ($E_{AC,d}$) and monthly ($E_{AC,m}$) energy generated by the solar PV power plant is given by Eqs. (1) and (2) [12],

* Corresponding author. Tel.: +91 79 2327 5428; fax: +91 79 2327 5030.
E-mail address: manoj.kumar@sse.pdpu.ac.in (M. Kumar).

http://dx.doi.org/10.1016/j.enconman.2014.01.013
0196-8904/

Nomenclature

T_C	working temperature of solar cell (Kelvin)
MPP	maximum power point
P_{MAX}	maximum power
FF	fill factor
η	efficiency
G_t	total in-plane solar radiation (W/m^2)
H_t	total in-plane solar insolation (kW h/m^2)
A_a	array area

Subscripts

deg	degradation
PV	photovoltaic
soil	soiling
temp	temperature
STC	standard test condition

$$E_{AC,d} = \sum_{t=1}^{t=24} E_{AC,t} \quad (1)$$

$$E_{AC,m} = \sum_{d=1}^{N} E_{AC,d} \quad (2)$$

where N is the number of days in the month.

The instantaneous energy output could be obtained by measuring the energy generated by the solar PV power plant after the DC/AC conversion.

The array yield (Y_A) is defined as the energy output from a PV array over a defined period (day, month or year) divided by its rated power [13] and is given by Eq. (3) as,

$$Y_A = \frac{E_{DC}}{P_{PV,rated}} \quad (3)$$

The daily array yield ($Y_{A,d}$) and monthly average daily array yield ($Y_{A,m}$) [14] are given by Eqs. (4) and (5) as follows

$$Y_{A,d} = \frac{E_{DC,d}}{P_{PV,rated}} \quad (4)$$

$$Y_{A,m} = \frac{1}{N}\sum_{d=1}^{N} Y_{A,d} \quad (5)$$

The final yield is defined as the annual, monthly or daily net AC energy output of the system divided by the rated power of the installed PV array at standard test conditions (STC) of 1 kW/m^2 solar irradiance and 25 °C cell temperature. This is a representative figure that enables comparison of similar solar PV power plant in a specific geographic region. It is independent on the type of mounting, vertical on a façade or inclined on a roof and also on the location. The annual final yield is given by Eq. (6) as [15],

$$Y_{F,a} = \frac{E_{AC,a}}{P_{PV,rated}} \quad (6)$$

The daily final yield ($Y_{F,d}$) and the monthly average daily final yield ($Y_{F,m}$) is given by Eq. (7),

$$Y_{F,d} = \frac{E_{AC,d}}{P_{PV,rated}} \text{ and } Y_{F,m} = \frac{1}{N}\sum_{d=1}^{N} Y_{F,d} \quad (7)$$

The reference yield is the total in-plane solar insolation H_t(kW h/m^2) divided by the array reference irradiance (1 kW/m^2). It is the number of peak sun-hours and is given by Eq. (8) [15]:

$$Y_R = \frac{H_t(\text{kW h/m}^2)}{1(\text{kW/m}^2)} \quad (8)$$

The performance ratio (PR) indicates the overall effect of losses on a solar PV array's normal power output depending on array temperature and incomplete utilization of incident solar radiation and system component inefficiencies or failures. The PR of a solar PV power plant indicates how close it approaches ideal performance during real operation and allows comparison of solar PV power plant s independent of location, tilt angle, orientation and their normal rated power capacity. The solar PV power plant efficiency is compared with the nominal efficiency of the photovoltaic generator under standard test conditions. Performance ratio is defined by Eq. (9) as follows [16,17],

$$\text{PR} = \frac{\eta_{sys}}{\eta_{STC}} = \frac{E_{AC}}{G_t}\frac{G_{STC}}{P_{AC,STC}} = \frac{E_{AC}}{G_t \eta_{STC}} \quad (9)$$

where

$$\eta_{sys} = \frac{E_{AC}}{A_a G_t} \text{ and } \eta_{STC} = \frac{P_{AC,STC}}{A_a G_{STC}} \quad (10)$$

Performance ratio indicates the overall effect of losses on a solar PV array's normal power output depending on array temperature and incomplete utilization of incident radiation. Performance ratio is also expressed by Eq. (11) [13,14,18]:

$$\text{PR} = \frac{Y_F}{Y_R} = \frac{E_{real}}{E_{ideal}} = \eta_{deg}\eta_{tem}\eta_{soil}\eta_{inv} \quad (11)$$

The capacity factor (CF) is a means to present the energy delivered by an electric power generating system. If the system delivers full rated power continuously, its CF would be unity. The capacity factor (CF) is defined as the ratio of the actual annual energy output to the amount of energy the solar PV power plant would generate if it is operated at full rated power ($P_{PV,rated}$) for 24 h per day for a year and is given by Eq. (12) [13],

$$\text{CF} = \frac{Y_{F,a}}{24 \times 365} = \frac{E_{DC,a}}{P_{PV,rated} \times 8760} = \frac{H_t \times PR}{P_{PV,rated} \times 8760} \quad (12)$$

The CF for a grid connected solar PV power plant is also given by Eq. (13) [19],

$$\text{CF} = \frac{\text{h/day } of \text{ ``}peak\ sun\text{''}}{24 \text{ h/day}} \quad (13)$$

Array capture losses (L_c) are due to the solar PV array losses and is given by Eq. (14) [13]:

$$L_c = Y_R - Y_A \quad (14)$$

System losses (L_s) are as a result of the inverter and is given by Eq. (15) [13],

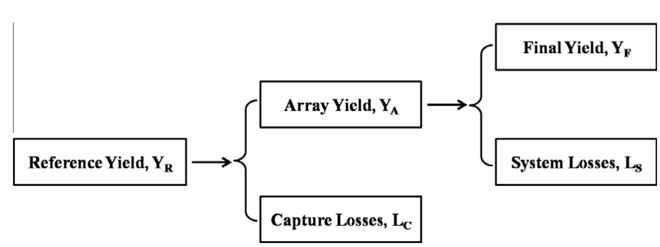

Fig. 1. Representation of relationships among normalized parameters.