Sustainable Energy Technologies and Assessments 15 (2016) 35–41

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

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

Original Research Article

Design, construction and performance test of an efficient large-scale solar simulator for investigation of solar thermal collectors

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ARTICLE INFO

Article history:
Received 4 July 2015
Revised 26 November 2015
Accepted 21 March 2016

Keywords:
Solar simulator
Light simulation
Light field
Solar thermal test

ABSTRACT

The performance of a thermal collector can be evaluated by determination of thermal efficiency in steady state test of solar simulators. This paper presents design and construction of an efficient multiple-lamp solar simulator for investigating the performance of the solar collectors for scientific and industrial purposes. Metal halid lamps are employed as source of irradiance. The uniformity of the irradiated surface was checked by simulation of the light field. This simulations are done in DIALux. The non-uniformity and instability, as factors that are described in EN 12975 standard, must be less than 15%. Also, the standard is determined, at least, 700 W/m^2 as average of irradiance for testing solar collectors. The amount of irradiance received by their radiated surface, which can vary from 100 W/m^2 to 1000 W/m^2, is controlled by changing the distance of testing surface from lamps and/or the number of lamps that is on. The performance of solar simulator was compared to Sun by testing a Compound Parabolic Concentrating (CPC) collector at Materials and Energy Research Center (MERC) in the city of Karaj. In the same conditions of test, the thermal efficiency of CPC collector was calculated with both sources of radiation from the solar simulator and Sun.

Introduction

Renewable energy has been in the center of attention in recent years due to the increasing need of energy. Availability and much less resulting pollution are some of the main characteristics of renewable energy. Energy demand of buildings, such as thermal and electrical energy, can be provided by solar energy in many places.

Iran has vast resources of fossil fuels but because of air pollution in big cities, many projects have been focusing in renewable energy. The use of solar energy is successfully feasible in many regions of Iran [1]. Southern Khorasan and Khuzestan provinces have significant potential of solar radiation and in some other stations, an annual average horizontal radiation of at least 500 W/m^2 was recorded, as described by Pouria [2]. In this respect, some projects pertaining to solar energy have been utilized and carried out by the Iran's Ministry of Energy [3]. Economic competitiveness and educational purposes have led to design and manufacture of this solar simulator. The solar simulators have been used to investigate the performance of solar collectors in controlled and standard experimental condition. In fact, it provides an effective and repeatable condition to test the performance of the solar thermal collectors.

Commercial lamps are applied in solar simulators so as to be capable of providing an environment that is similar to daily changes of radiated sunlight especially in course of illumination and temperature. An environment recreation laboratory can be installed indoor or outdoor. Then, performance and efficiency of the collectors are examined within an artificial environment in the laboratory that is similar to the conditions of natural environment. A solar simulator uses lamp to simulate sunlight. However, lamp cannot create all wavelengths of sunlight [4]. For comparative goals, indoor tests are an appropriate and quick way to achieve results.

In 2001, Institute for Solar Energy (ISE) has designed and installed a solar simulation system for indoor solar thermal testing. In fact, outdoor test condition was simulated by indoor test facility to complement the real condition of out. The installed solar simulator was enabled to evaluate the performance of solar thermal collectors. It was designed and manufactured in 2004 and installed in Belo Horizonte [5]. A company in Freiburg has been developing and building test stands in cooperation with Fraunhofer ISE. The indoor

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http://dx.doi.org/10.1016/j.seta.2016.03.004

and outdoor test stands have used for certification and for R&D purposes. Their test stands were installed at the French national solar energy institute, a German collector manufactory and a Brazilian Research Institute [6].

Shogo and Kosuke have studied a LED solar simulator for testing solar cell. They used four-color lamps and the distance between solar cell and light source was changed for adapting the value of radiation [7]. Anon et al. [8] constructed four single-color LED simulators and one multi-color LED simulator for characterization of solar cells. They obtained high irradiance by employing high pulsing voltages to LEDs. Results from the red and blue LED simulators were in good agreement by using correction methods of the IEC 891 Standard. Kolberg et al. [9] tested different kinds of LED optics for achieving the best relation between homogeneity and intensity. The constructed fully LED based solar simulator of them have used for PV industry. It has full wavelength range of interest for Si-PV with an extension in the UV, matching AM1.5 g from 350 nm to 1100 nm by applying apply 22 different LED packages [10].

Bancha et al. used a 1000 W halogen lamp as heat source to simulate solar radiation on Stirling engine. They have measured radiation intensity at various distances to evaluate the performance of their solar simulator [11]. In one study was conducted by Fatih et al. [12], 400 W and 1000 W halogen lamps as a heat source has been used for evaluating the performance of a beta type Stirling engine which worked at relatively lower temperatures. The temperature of cavity adjacent to the hot end of the displacer cylinder of Stirling engine has been determined about 623 K and 873 K for 400 W and 1000 W halogen lamp respectively.

A 42-kW high-flux solar simulator with 6 kW Xenon lamps has been built at IMDEA Energy Institute, Spain [13]. It could be used for analyzing processes under concentrating solar energy conditions like central receivers in concentrating solar power plants and solar thermo-chemical reactors [14]. The real flux distribution has been studied by experimental characterizations of solar simulator. High-flux solar simulator scan was used for controlling conditions and conducting high-temperature and thermo-chemical research. The construction of one 84 kW solar simulator with an array of 12 xenon-arc lamps and silicone-on-glass Fresnel lenses as the optical concentrator was reported by Wang et al. [15]. It might be used for experimental platform for high flux solar receiver, thermo-chemical reactor research and advanced high-temperature material tests. Javad et al. [16] reported characterization of a high flux solar simulator that can be used for solar thermal, thermo-chemical and high concentration photovoltaic research. The flux mapping method was used to evaluate flux distribution, temporal instability, spatial non-uniformity, peak flux, conversion efficiency and power intercepted on the focal plane of it. Peak flux of 3583 kW/m^2, temporal instability less than 3%, and cumulative beam power of 1.642 kW at a circular target radius of 110 mm were reported by them. A solar simulator consisting of linear focus units and a fluid circulation system has been constructed by Okuhara et al. [17], linear focal area had 4 m long receiver with a 5 kW Xenon-short arc lamp for each unit and the average flux of 24.3 kW/m^2 was achieved along the half-round surface of the receiver tube.

A primary optics for solar concentrator by using an achromatic Fresnel doublet was designed by Fabian et al. [18]. They have determined the performance of achromatic Fresnel doublet by means of a solar simulator for comparing paraxial theory and ray-tracing simulations. A good agreement between experimental and theory was observed and shown tolerating the achromatic Fresnel doublet for manufacturing errors and uncertainty.

Kockott and Schoenlein [19] have determined factors characterizing the grade of fitting in quantity for various available solar simulators for chemical and material test purposes. They indicated characteristic factors for different wavelength ranges and the grade of fitting on the spectral distribution of solar simulators for defining "reference sun". Suren et al. [20] have recommended some advises for device masking and efficiency characterization that help determining the efficiency in a standard organic solar cell accurately. They found that the most substantial variation in the measured efficiency is caused by light field non-homogeneity and a large diffuse component in combination with masking. Monte Carlo Ray Tracing (MCRT) method was applied for numerical simulation of temperature variation of complicated structure satellite surfaces by Liu et al. [21]. They have studied the non-uniformity and the instability of solar radiation of solar simulator for analysis variation of antenna temperature fields in detail.

The time-resolved spectra of the irradiation emitted from metal halide (6 kW) and xenon arc (5 kW) lamps employed by solar simulators has reported by Xue et al. [22]. The irradiation from the xenon arc lamp was found to be spectrally more stable with time than metal halide lamp, especially at the shorter-wavelengths of below 550 nm. But the time-averaged spectrum of the solar simulator with metal halide lamp matches the solar spectrum better than xenon arc lamp.

A solar simulator was developed and tested successfully by Daniel et al. [23]. It was utilized with an array of seven 1500 W metal halide lamps, output fluxes greater than 60 kW/m^2 in the peak point and 45 kW/m^2 in averages. These were achieved across the diameter of 38 cm output aperture. It has used to studying optical melting and light absorption behavior of molten salts.

Qinglong et al. [24] have built a large scale solar simulator whit 188 metal halide lamps (400 W). The average radiation could vary between 150 and 1100 W/m^2 by varying the number of lamp and/or the lamp to area distance.

In this paper, information about various parts of set up and also simulation and design aspects of one modified constructed solar simulator, with a novel low cost and energy saving design, are reported. It has specially explained the optimized generation of a solar simulator with using mirror-like stainless steel walls on besides and special test platform that is able to change tilt and radiation of collectors. It consumes smaller amount of energy in comparison with similar systems that high weight of light field has moved for adapting radiation on irradiated surface. Energy demand of metal halide lamps is just 24 kW which is fewer than similar solar simulator used metal halide lamps for thermal test. The aim of this project was one design with the least energy consumption as well as applying metal halide lamps and satisfying standard's requirements (EN 12975). For evaluation of the solar simulator performance, a CPC collector was tested with the solar simulator and its results have compared to the experimental study with Sun at MERC in the city of Karaj.

Test stand

The test stand consists of two components, solar simulator and collector test platform.

Solar simulator

In fact, the solar simulator is the main part of the test stand, as it provides irradiance and required thermal energy for collector testing. It contains a light field and an efficient system of controlling amount and angle of incidence on irradiated surface of collector.

Light field is the most important part of the solar simulator. Matching spectrum resembles to Sun, with an acceptable uniformity of irradiance in the irradiated surface and having stable irradiance over the time of test, are design factor of an authority light source for scientific aims. The spectrum match depends on the kind of lamps which have a spectral distribution closely resembling the