Calculate the Reflected Hourly Solar Radiation by Mirror Surfaces of Solar Concentrators Parabolic Trough

Moafaq K.S. Al-Ghezi

***Abstract* — This paper aimed for calculating throughput characteristics of a parabolic trough solar collector throughout the day, it must be calculated the solar radiation every hour during the day for each month. The long run models give the distribution of the average hourly of the total radiation through the average day of each month. According to this long run models, the rate of daily global and scattered radiation on a horizontal surface are given, $\overline{G_h}$ and $\overline{S_h}$, consecutively, it is potential to predict long run hourly global and scattered solar radiation: I_h and $I_{S,h}$. The values of $\overline{G_h}$ *and* $\overline{S_h}$ can be get either from ground-based measurements or satellite data. The satellite information offer data regarding solar radiation and environmental condition in locations wherever ground measure values don't seem to be accessible. The model of daily integration (DI), as an hourly radiation model was used to calculate the solar radiation.**

Index Terms —– Beam radiation; Global solar radiation; Diffused radiation; and meteorological data Solar Radiation.

I. Introduction

Global energy policy is directed towards the use of renewable energies in various fields, in order to reduce global warming and reduce emissions of toxic gases into the atmosphere and other environmental factors [1]. The fact that renewable energy sources are inexhaustible, where it can be used in the production of electricity or heating of housing and public utilities, as well as use in the production of hot water for human use or industrial [2]. Solar energy is one of the most important types of renewable energy, as it is reaching the earth a flood of photons loaded with energy to the surface of the earth as a result of continuous explosions inside the solar sphere [3]. From the above, the importance of solar energy and its applications is shown, and it seems that it is important to calculate the solar radiation or measure it to conduct any study relating to the applications of solar energy [4].

The energy policy in Iraq is moving towards the use of solar energy in various fields and encouraging the establishment of projects that use renewable energies, especially solar energy, because of Iraq's suffering from high rates of environmental pollution and the high temperatures resulting from the expansion of the phenomenon of desertification and the decline of green areas [5]. The desertification came as a result of the lack of water needed for agriculture and neglect in the agricultural sector because of wars fought by the country in recent decades [6]. In addition, the increase of carbon dioxide in the atmosphere, which was the result of the increase in the cars on the streets and a significant increase in the number of electro-power generators operate on diesel fuel [7]. As a result of all of the above, the government in this country has tried to reduce this deterioration in the ecosystem and has made many plans at the near and long term in various fields, including energy [8]. For example in terms of electric power, in 2008, the government illuminated most of the streets of Iraqi cities with solar lamps powered by solar photovoltaic panels, which converts the photovoltaic energy falling on the surfaces of these panels into electrical energy with known physical mechanisms that cannot be studied in detail during this study [9, 10].

The Iraqi government encourages citizens to use solar heaters, which are used in the production of hot water for domestic use by converting the energy carried by solar radiation, which is absorbed by the solar heater pipes that are usually made of copper or iron or any metal has the viability of thermal conductivity to thermal energy used to raise the temperature of the water flow inside these pipes [11]. Besides, Iraqi government planned to build solar power stations and has been limited this plan into two types of plants. One of which produces direct electrical energy by the use of photovoltaic cells, which produce a direct current DC that can be stored in batteries, which store electricity that is later converted into an alternating current (AC) by using the inverter [12]. Some parts of this type of solar power stations have been completed during the year 2017 [13]. The other type of solar plants is a station that produces electricity indirectly through the production of superheated steam, which is used in other stages in the production of electricity [14].

The steam in these stations is produced by the use of solar radiation concentrators, which focus the solar radiation on the heat transfer fluid and the most important types of these concentrates are the mirrors of the parabolic trough solar collector which will be discussed later. A country such as Iraq is exposed to a huge amount of solar radiation throughout the year [15]. Iraq has a hot dry tropical climate in the summer and cool rainy in winter, noting that the winter period is short compared to the long summer with a high-intensity solar radiation in the summer [16].

In general, the average sunny days in Iraq were found to be approximately 333 days, while the weather was cloudy and dusty for 32 days [17]. These potential radiological solar available to Iraq made it in the forefront of countries that can

Moafaq K.S. Al-Ghezi, is currently lecture in University of Technology, Energy and renewable energies technology center, Baghdad, Iraq. Email; -11020@uotechnology.edu.iq

be taken advantage of solar energy in various fields, especially electricity generation and water heating to initiate any work related to the applications of solar energy needs. Detailed knowledge about values of solar radiation and its types will be introduced in this study.

Solar plants are similar to conventional power plants, but they differ only in terms of method of generating steam [18]. In traditional power plants, steam is produced by burning fossil fuels such as oil, gas or even coal and other types of fuel [19]. In solar power plants, steam is produced by concentrating the solar radiations through mirrors that are in the shape of a flat, dish or parabolic trough [20].

A high concentration of solar radiation is required when solar concentrators that contain reflective mirrors are used [21]. The most important types of solar concentrators are the parabolic trough solar collector, which reverse and focus the solar radiation to which it is exposed by mirrors [22]. The mirrors represent the reflective surface in the solar collector [23]. Concentrated radiation is collected and absorbed by the receiver tube which runs along the solar axis, this process will heat the heat transfer fluid that flows into the absorber tube of heat to a high temperature that exceeds 400 °C, which are transfer to generate superheated steam through heat exchangers and thus it used to produce electricity [24].

In this study, emphasis will be placed on stations that use concentrators for solar radiation in the form of parabola, it is noted that the work of this type of stations depends mainly on the intensity of solar radiation so that there should be accurate information about the details of solar radiation for each hour of the day and throughout the year. A mathematical model will be constructed based on a set of parameters that are calculated or measured and formulated to solve mathematical equations governing by using computer technology and mathematical methods to generate the steam needed to rotate the turbine in the solar power plants.

II. THEORETICAL STUDY AND MATHEMATICAL MODEL

When solar radiation enters the atmosphere, it suffers from reflection and scattering as well as part of it is absorbed before it reaches the Earth's surface due to dust in the air, water vapour, and air [25]. Part of the radiation that reaches the surface of the earth or falls on objects without any change in direction is called direct (beam) radiation, while the radiation reflected on the surfaces and coming from the sky is called scattered (diffuse) radiation [26].

The total instantaneous solar radiation on the horizontal surface, I_h, is the sum of the beam (direct) radiation, $I_{b,h}$, and the celestial diffuse radiation $I_{S,h}$:

$$I_h = I_{b,h} + I_{S,h} \tag{1}$$

As shown in Figure 1, I_h can be expressed as [27]:

$$I_h = I_{b,N} \cos z + I_{S,h} \tag{2}$$

Or

$$I_h = I_{b,N} \sin \alpha + I_{S,h} \tag{3}$$

The hourly beam radiation, $I_{b,h}$, obtained from the equation (1):

$$I_{b,h} = I_h - I_{S,h} \tag{4}$$

The introduction of the hourly daily coefficients r_d and r_t:

$$r_d = \frac{I_{S,h}}{\overline{S}_h} \tag{5}$$

$$r_t = \frac{I_h}{\overline{G}_h} \tag{6}$$

Where the beam radiation:

$$I_{b,h} = r_t \overline{G}_h - r_d \overline{S}_h \tag{7}$$

Liu and Jordan [27] showed that r_d is well defined according to figure 2 [28]:

$$r_d = \frac{\pi}{24} \frac{\cos h - \cos h_{ss}}{\sin h_{ss} - h_{ss} \cos h_{ss}} \tag{8}$$

The ratio of horizontal hourly radiation to the total horizontal daily radiation, r_t , is defined as:

$$r_t = r_d \frac{1 + q(a_2/a_1)A(h_{ss}) r_d (24/\pi)}{1 + q(a_2/a_1)B(h_{ss})/A(h_{ss})} \tag{9}$$

Where (a_2/a_1) represents the effect of atmospheric extinction, a_1 and a_2 are obtained from a plurality of least-squares fit:

$$a_1 = 0.41341 K_t + 0.61197 K_t^2 - 0.01886 K_t S_{max} + 0.00759 S_{max} \tag{10}$$

$$q = \cos L \cos \delta_s \tag{11}$$

$$A(h_{ss}) = \sin h_{ss} - h_{ss} \cos h_{ss} \tag{12}$$

$$a_2 = Max(0.054,\ 0.28116 + 2.2475 K_t - 1.7611 K_t^2 - 1.84535\ h_o + 1.681\ h_o^3) \tag{13}$$

Where h_o is the daily average solar height outside the atmosphere, defined as:

$$h_o = q A(h_{ss}) / h_{ss} \tag{14}$$

and h_{ss} is the hour angle of sunset and $B(h_{ss})$ is defined as:

$$B(h_{ss}) = h_{ss}(0.5 + \cos^2 h_{ss}) - 0.75 \sin(2 h_{ss}) \tag{15}$$

For a parabolic trough concentrating solar collector, the direct radiation on the aperture area, $I_{b,c}$, is needed only [27, 29]. The direct radiation, $I_{b,c}$, is calculated by the formula:

$$I_{b,c} = (r_t \overline{G}_h - r_d \overline{S}_h) \frac{\cos i}{\sin \alpha} \tag{16}$$

Where i is the incidence angle, which depends on the tracking method and the location of the sun.

III. RESULTS AND DISCUSSION

Figure 3 shows the average over 51 years of hourly values of total, direct and scattered solar radiation on a horizontal surface for 21 March, 21 June, 21 September, and 21 December. It is clear that the maximum value corresponds to June, while the minimum solar radiation value falls on the month of December. The difference in radiation values is due to many factors. One of which is the climatic conditions, such as the distribution of total precipitation, clarity and cloudiness, a dusty and misty sky, relative humidity and air temperature. From the graphs it becomes clear that the solar radiation intensifies from morning to noon and then decreases by the evening and this is the standard result for all days throughout the year.

Figure 3 represents the changes in the hourly total, direct and diffuse solar radiation on a horizontal surface in Baghdad during the 21 March, 21 June, 21 September and 21 December. As any wrong information about the intensity of solar radiation will lead to the failure of the design of the station or at least stop working. In the summer, solar radiation is most intense in many areas of the world, especially in Iraqi territory, as shown in Figure 3. Where we get excess heating and as a result of this must either get rid of this increase in heat by skew solar panels from the path of the fall of radiation to reduce the proportion of concentrated and reflected solar radiation on the surface of the absorption tube. This method is used in the absence of a mechanism for thermal storage or excess heat storage tanks in the thermal storage system that can be used in the operation of the station during the night hours and in which solar radiation is almost non-existent.

IV. CONCLUSION

It is clear from the results obtained that the three types of solar radiation; total, diffuse and beam radiation are behave in a similar manner. Their values start low in the early morning and increase during the day until they reach the peak at midday and then fall back to their lowest levels at sunset. On the other hand, the solar radiation in general will be at its maximum value in the month of June and fall to minimum value in December.

When designing a solar powered plant, the intensity of the solar radiation should be changed as the seasons change in order to reach a design.

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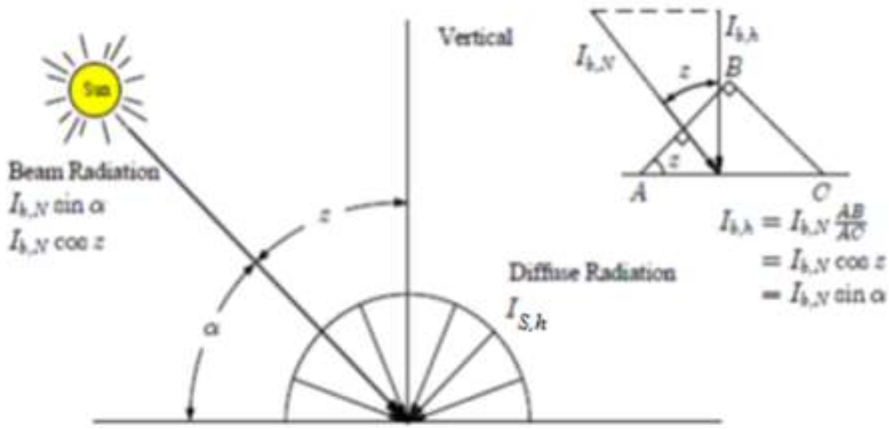
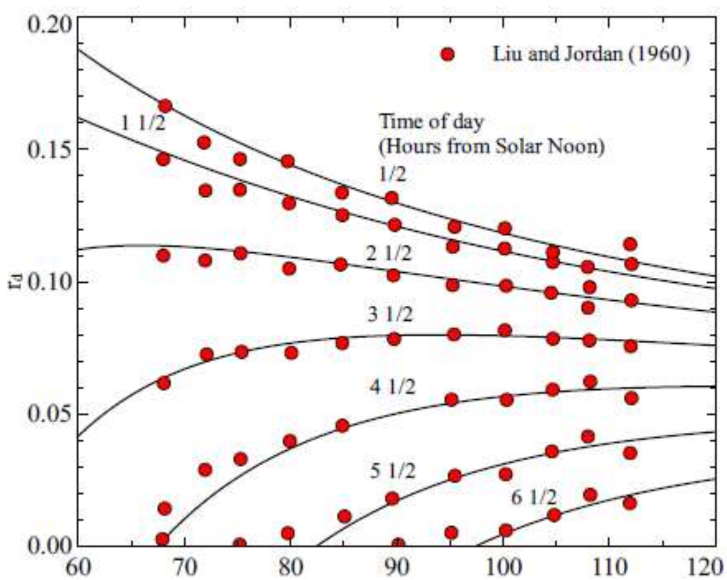


Fig.1: The solar radiation on a horizontal surface, adapted from [26].



(Sunset hour angle h_{ss}, in degrees from solar noon)

Fig.2: The change in r_d, the diffuse conversion coefficient, with the hourly angle of sunset h_{ss} for different times of the day. It is taken from [27, 28].

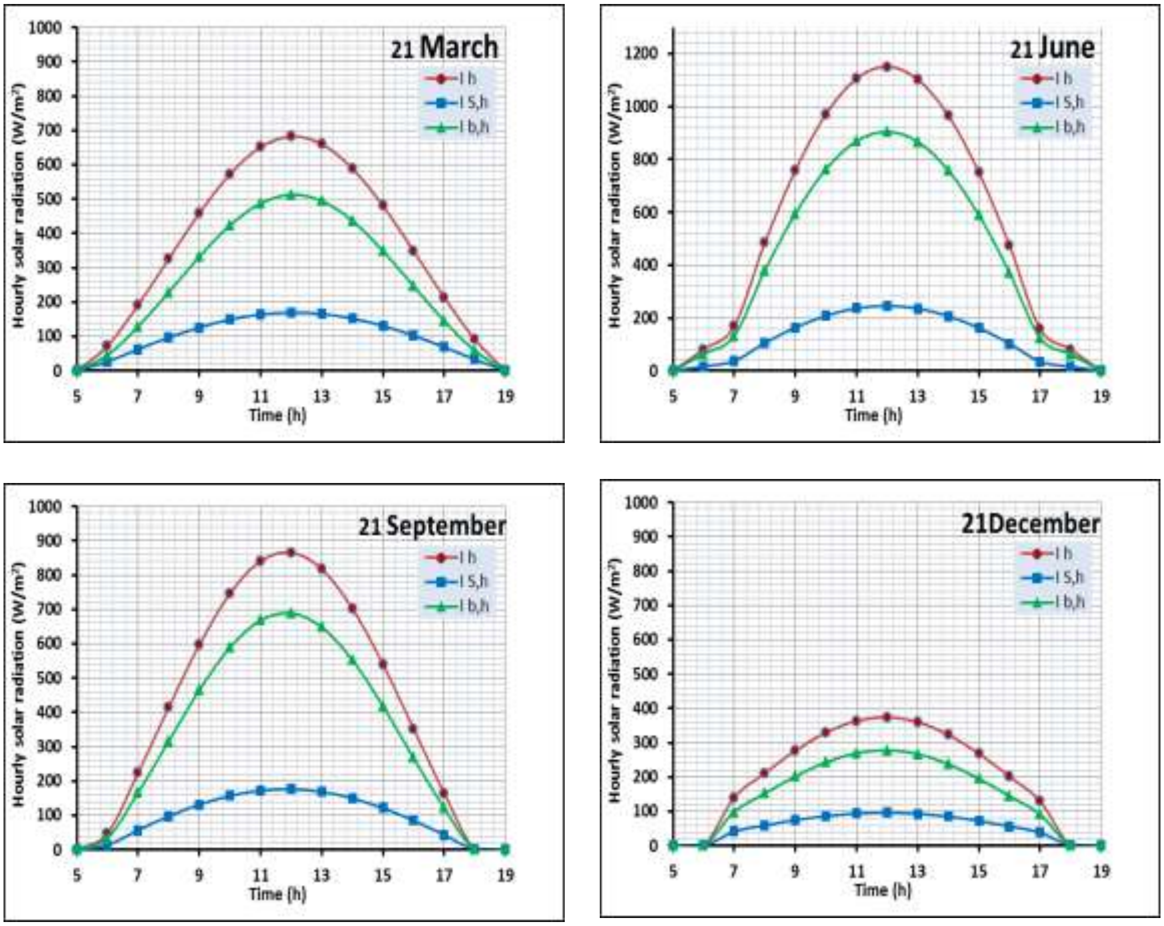


Fig. 3: Changes in the hourly total direct and diffuse solar radiation on a horizontal surface in Baghdad during the 21 March, 21 June, 21September and 21December.