All about Solar Energy

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Abstract— We all know very well that today's life cannot be imagined without power (Energy). As the time is passing the more and more use of energy demand is increasing. Traditionally only conventional source of energy was available to us. But they are limited, offering significant pollution, less efficient. That's why the world felt the maximum utilization of non conventional energy resources like wind, solar, fossil energy etc. Among all solar energy is considered as best because of some facts like easy and ample availability, pollution free, economical etc. Amount of solar energy solely depends on amount of solar radiation received. This paper will deal with differences between solar energy and solar radiation, solar radiation forecasting and solar radiation estimation. The reader will also come to know about the main use of solar energy as water heating, photovoltaic panels, etc. By going through this paper one can get the idea of various solar radiation measuring instruments like Pyranometer, Pyrheliometer etc. along with all paper will give detailed idea of limitations of conventional energies, future scope and need of non-conventional energy resources with all the advantages of solar energy over all other available non-conventional energies.

Key words: Solar Radiation, Estimation Models, MAPE, TS, MBE, RMSE, Regression, Pyrheliometer, Pyranometer

I. INTRODUCTION

Our life could not be imagined without energy (Power). It has become an integral part of our day to day life. Traditionally we were dependent on conventional source of energy like coal, hydroelectric etc. But they are limited resource also they offer residue or pollution to the environment. This is non-desirable. These are the main reasons the researchers inclined themselves towards the maximum exploration and use optimal use of non-conventional energy resources. The mainly available nonconventional source of energy is solar energy, wind energy, biomass energy, ocean energy (tidal energy, wave energy and ocean thermal energy), geothermal energy, nuclear energy etc. Among all solar energy is most preferable. The Sun is the most important and unique type star of the solar system. It is having tremendous amount of energy. Energy comes from nucleus fission. This energy is released into space mainly in the form of electromagnetic radiation which is experienced as heat and light. As per NASA only one hour of sunlight is more than sufficient to meet the energy demand of world for whole year. It releases approximately 1,20,000 TW of energy in a hour. Also solar energy is totally pollution and residue free. The use of solar energy mainly depends on amount of solar radiation received. So, the solar radiation needs to be predicted. Before prediction it should be noted that solar radiation mainly dependent on various meteorological parameters like ambient temperature, wind speed, movement of clouds.

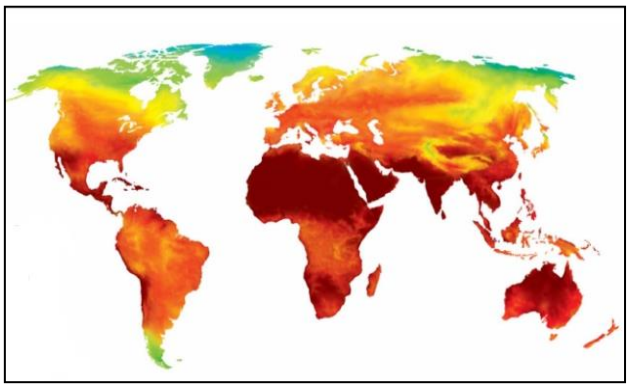

Fig. 1: world solar energy potential by NASA

From Fig. 1, it is clear that tropic of cancer passes through India. But we are lagging much in the use of solar energy. Actually now also we are not able to predict the amount of solar radiation that is going to be received by us. Unfortunately maximum of solar energy labs are situated with developed countries because they are highly costly. In Gurgaon a solar study lab is there.

II. SOLAR RADIATION AND SOLAR ENERGY

Sl No	Solar Radiation	Solar Energy
1	This is the radiation received from the sun.	Conservation of radiation and conversion into electricity.
2	Known as short wave radiation.	Facilitates use of Concentrating Solar Power (CSP)
3	Have many forms like visible light, radio waves, heat (infrared), ultraviolet rays.	Simply the energy provided by the sun.
4	Spectrum is closed to black body.	Solar energy can be used in architecture planning.
5	Barrier of solar radiation is atmosphere. 26% reflected back by clouds and 18% absorbed by atmosphere.	Originates with the thermonuclear fusion reaction occurring in the sun.

Table 1: Solar Radiation and Solar Energy

A. Estimation and Forecasting

Sl No	Estimation	Forecasting
1	Estimation refers to act or an instance of estimating.	Forecasting is the process of making a forecast or prediction.
2	Defined as the amount, extent, position, size or value reached in an	Solar power forecasting involves knowledge of the sun's path, the

	estimate.	atmospheric conditions and the scattering processes.
3	To form approximate idea of distance, size or cost.	Provides benchmark for firms which have long term perspective of operations.
4	This is usable even if input data may be incomplete or uncertain.	Used by companies to determine allocation of budgets.
5	Estimation involves "using the value of statistic derived from a sample to estimate the value of corresponding population parameter.	Forecast information is useful for efficient use, management of grid for energy trending.
6	This is the process of finding an estimate	Mainly of three types now-casting (3-4 hours), short term casting (up to 7 days ahead), long term (monthly or yearly)

Table 2: Estimation and Forecasting

B. Geometry of Sun

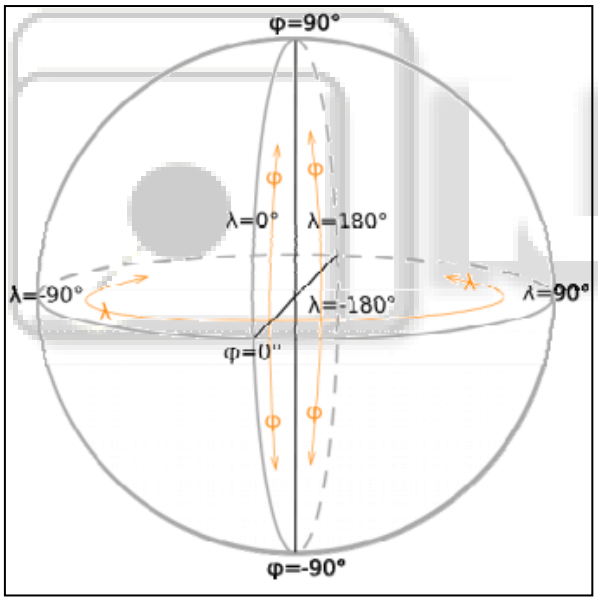

Fig. 2: concepts of latitude and longitude

Longitudes, λ, is defined along with east/west, means either to east or to west of the Greenwich meridian. Thus, the latitude varies from - 900 to + 900 and the longitude varies from 00 to 1800 E or 00 to 1800 W.

The latitude of a point on the earth's surface is the angle between the equatorial plane and a line that passes through that point and is normal to the surface. The North Pole is 90° N; the South Pole is 90° S. The 0° parallel of latitude is designated the equator, the fundamental plane of all geographic coordinate systems.

λ (Longitude), on is the angle east or west from a reference meridian to another meridian that passes through the point. Latitude and longitude specify the position of any location on the planet, but do not account for altitude or depth.

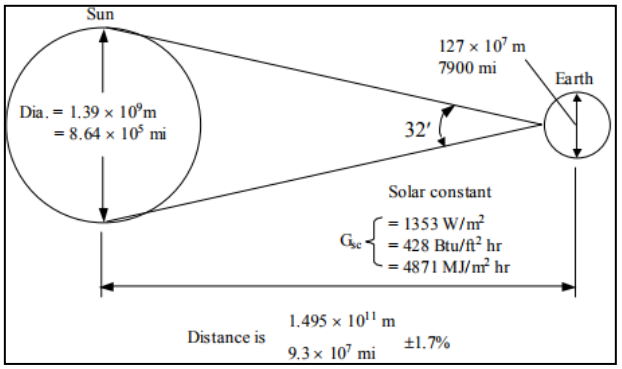

Fig. 3: Sun - Earth relationship

Sun-earth relationships are shown by fig 3. Due to the elliptic orbit of the earth around the sun the distance between sun and earth varies by 1.7%. The mean distance is 1.495 x 1011 m. 32' is subtended by sun with the earth. The diameter of the sun is 1.39 x 109 m.

Intensity of solar radiation depends on the distance of Sun with Earth that can be received by earth. The elliptic motion (see, Fig. 3) of the earth round the sun causes the seasonal variation in the solar radiation as received by the earth.

C. Application of Solar Energy

1) Solar Water Heating:

Solar energy may be used in water heating both for domestic and industrial purpose. The traditional available methods of

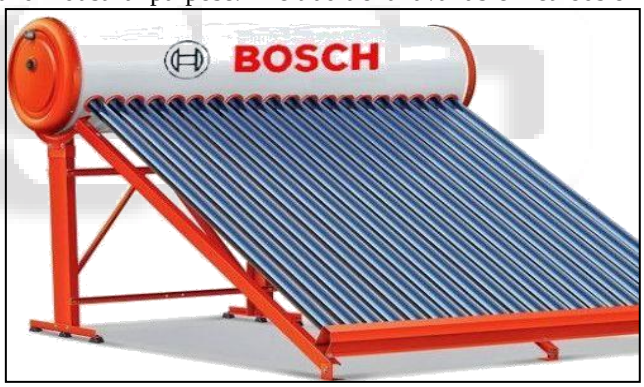

Fig. 4: Roof top panel for water heating

water heating like geyser consumes lot of electricity. But solar heater is cost effective and efficient. There are mainly two types of solar heater is there

a) Active, closed loop solar heater:

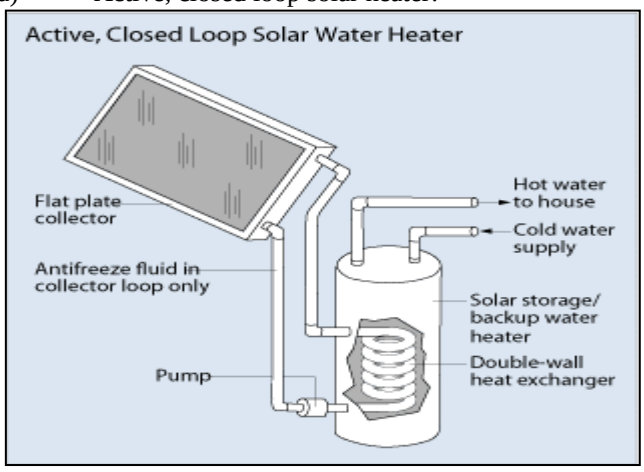

Fig. 5: Active closed loop solar water heater

In this flat plate collector is connected with solar water heater via antifreeze fluid loop and pump. Two types of points are there with heater one is for cold water supply and another for hot water supply. Inside the heater double wall heat exchanger is there which heats the water.

b) Passive, batch solar water heater:

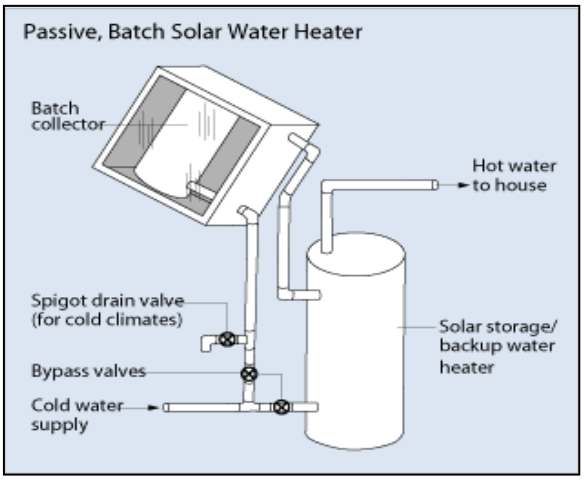

Fig. 6: Passive, Batch solar water heater

Passive solar water heater is different from active heater. Instead of flat pane collector batch collector is used. Here heat exchanger is also not required. With the help of control valve the inlet is regulated.

D. Conversion of solar energy into electricity

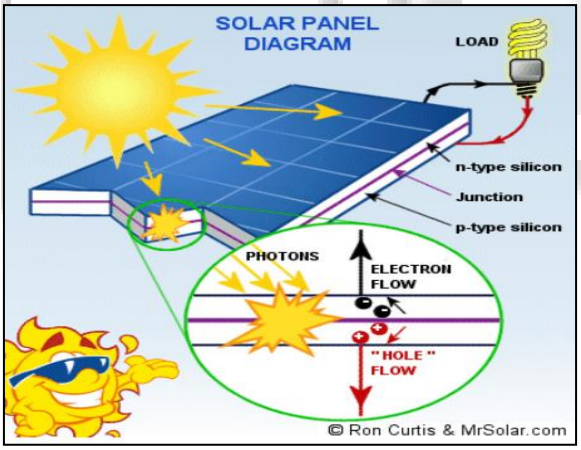

Fig. 7: PV panel for solar energy conversion into electricity

Photovoltaic mechanism is used for conversion of solar energy into electricity. PV panels consist of semiconductors. PV cell have two types of semiconductors one with positively charged and another with negatively charged. When light falls on the semiconductor, the electric field across the junction between these two layers causes electric current. The greater the intensity of light, the higher is the flow of electricity.

III. Solar Radiation Measurement [7]

Measuring instruments are required to measure energy transferred by solar radiation to the surface of earth. These instruments measure the heating effect of direct and diffuse solar radiation. Two main measuring instruments are there one is Pyrheliometer which is used to measure direct normal (beam) radiation and second is Pyranometer which measures the total radiation.

Figure 8 is of pyrheliometer which consists of a detector at far end with collimating tube. The aperture angle of the device is 5.7^0. The detector has multi junction thermopile which has blackened surface. To minimize sensitivity to variations in the ambient temperature, temperature compensation is provided. The temperature of the thermopile is a measure of solar flux incident on it. The output is in DC voltage (in milivolt). This voltage can be converted into equivalent solar flux with the help of calibration constant provided by Eppley Labratories.

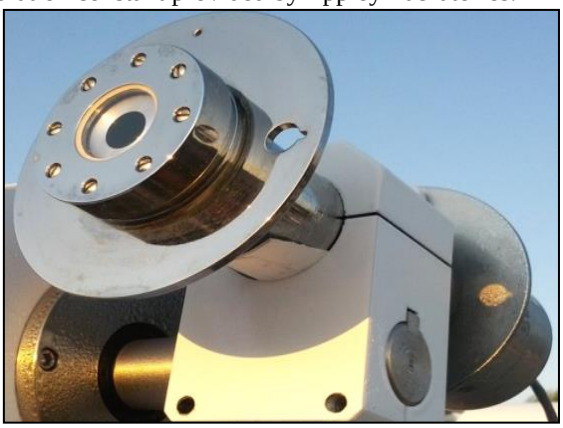

Fig. 8: Eppley normal incidence pyrheliometer (http://www.eppleylab.com)

Figure 9 is of precision pyranometer. To ensure proper cosine effect and temperature compensation, two concentric hemispherical are optically grounded. Like pyrheliometer, pyranometer also uses thermopile detector. Although pyranometer can be mounted in any orientation, still then it is generally oriented horizontally to measre solar flux. Pyranometer can be fitted with a shading ring to block the beam or direct solar radiation.

Fig. 9: Eppley precision pyranometer (http://www.eppleylab.com)

A. Solar Radiation Estimation Models

Lot of approaches has been made to calculate monthly/yearly daily radiation on horizontal surface in absence of H_o. The value of H_o may be calculated as below

$$Ho = \frac{24}{\pi} I_{sc} \left[1 + 0.33 \cos\cos \frac{360}{365} n\right] [\sin \omega_{ss} \cos \varphi \cos \delta + \omega_{ss} \sin \varphi \sin \delta]$$

Where $\delta = 23.45\left[\sin\frac{360}{365}(284+n)\right]$ and $\cos\omega_{ss} = -\tan\varphi\ \tan\delta$

There are three basic models for estimation of daily global solar radiation from sunshine hours are below [6].

1) Linear Model:

$$\frac{H_g}{H_o} = a_1 + b_1\left(\frac{S}{S_0}\right)$$

2) Quadratic Model:

$$\frac{H_g}{H_o} = a_2 + b_2\left(\frac{S}{S_0}\right) + c_2\left(\frac{S}{S_0}\right)^2$$

3) Cubic Model:

$$\frac{H_g}{H_o} = a_3 + b_3\left(\frac{S}{S_0}\right) + c_3\left(\frac{S}{S_0}\right)^2 + d_3\left(\frac{S}{S_0}\right)^3$$

a_i, b_i, c_i, d_i can be obtained for all the above by regression methods. Based on above lot of models has been developed few of them are below [5].

4) Angstrom Prescott Model:

The regression equation of angstrom type is most popular model. In this the regression constant a and b depends on seasonal changes and latitude

$$\frac{H_g}{H_o} = a + b(S)$$

5) Rietveld Model:

By observation Reitveld found that a is linearly whereas b hyperbolically related to the mean value of S, for S < 0.4

$$\frac{H_g}{H_o} = 0.18 + 0.62(S)$$

6) Ogleman Model:

This model gives the use of correlation which relates solar radiation in quadratic form as

$$\frac{H_g}{H_o} = 0.195 + 0.675(S) - 0.142\ (S)^2$$

7) Akinoglu Model:

Likewise Ogkema, Akinoglu aso suggested an equation whose coefficients have similar values independent of test locations

$$\frac{H_g}{H_o} = 0.29\cos\varphi + 0.52(S)$$

8) Gopinathan Model:

This model establishes relationship of a and b with latitude, elevation and sunshine hours.

$$a = -0.309 + 0.539\cos\varphi - 0.0693\,h + 0.290\,(S)$$
$$b = 1.527 - 1.027\cos\varphi + 0.0926h - 0.359(S)$$
$$\frac{H_g}{H_o} = 0.32 + 0.42(S)$$

9) Sangeeta et al. Model:

In this model a and b relates to latitude and sunshine hours only as

$$a = -0.110 + 0.235\cos\varphi + 0.323\,(S)$$
$$b = 1.449 - 0.553\cos\varphi - 0.694(S)$$
$$\frac{H_g}{H_o} = 0.29 + 0.52(S)$$

B. Performance Evaluation of Models

1) Mean Bias Error (MBE):

$$MBE = \frac{1}{k}\sum(G^i_{estimated} - G^i_{measured})$$

MBE gives long term performance. If over estimated in the predicted values are there then MBE is positive. If the predicted value is under estimation then MBE is negative.

2) Root Mean Square Error (RMSE):

This is defined as

$$RMSE = \sqrt{\left(\frac{1}{k}\sum(G^i_{estimated} - G^i_{measured})2\right)}$$

In ideal case RMSE is zero, otherwise it is positive.

3) Mean Absolute Percentage Error (MAPE):

$$MAPE = \frac{100}{k}\sum\left|\frac{(G^i_{estimated} - G^i_{measured})}{G^i_{measured}}\right|$$

MAPE is always positive. This avoids error cancelation problems.

4) The Test Static (TS):

$$TS = \sqrt{[(k-1)MBE^2/(RMSE^2 - MBE^2)]}$$

TS conclude about the model that it is statistically significant or not for a particular level of confidence.

IV. Conclusions

This paper gives study of solar radiation estimation and method of evaluation of their performance. Also paper gives idea behind importance of solar energy. After going through this paper reader will get clear concept of solar radiation estimation devices and various estimation models

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