LOW COST DIGITAL SOLAR INSOLATION METER

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Abstract—Terrestrial solar insolation measurement is of fundamental importance for the evaluation and deployment of solar renewable energy systems. Standard sophisticated instruments like Pyranometer and Pyrheliometer are not suitable for large-scale use because of high cost, poor commercial availability and need of specialized knowledge for their handling. In this research work, an attempt has been made to develop a handy and cost effective digital solar insolation meter, which can be used widely by common users to gather ample quantity of measurement data. Test results were almost identical to those of a calibrated standard analog insolation meter

Keywords—Insolation, Pyranometer, Solar Photo Voltaic (SPV), and Solar radiation (G).

1. Introduction

The designing and development of solar renewable energy systems are depending on the measurement of broadband and spectral terrestrial solar radiation. The renewable energy sector depends upon the seasonal and hourly assessment of accessible resources for designing their renewable energy products. Solar radiation is the fuel for solar-based renewable energy technologies such as Solar Photo Voltaic (SPV) and Solar Thermal (ST) conversion systems [1, 2]. Solar radiation inconsistency has a noteworthy impact on the performance of solar energy conversion systems [3]. That is why, design estimates of solar energy systems has to be initialized based on adequate measured data. In this paper, authors have tried to conquer attempted a handy and cost effective digital Incident Solar Insolation meter.

2. Solar Radiation Measurement

The total hemispherical solar radiation (G) received by a horizontal surface is the sum total of two components.

Direct beam radiation (B) from the solar disk projected on the surface (being modified by the cosine of the incidence angle of the beam, (I), Diffuse radiation or Sky radiation (D), which is scattered by atmospheric layers of the sky dome. The expression [4] for this relation is

$$G = B\cos(I) + D \qquad (1)$$

Standard instruments used for terrestrial radiation measurement are usually Pyranometer, Pyrheliometer and Shaded Pyranometer etc, as shown in Figure 1.

Total hemispherical radiation can be measured by pyranometers that respond to radiation within 2π steradian (hemispherical) field of view.

Pyrheliometers, being a narrow field of view instrument (5.0^o to 5.8^o); can measure nearly collimated radiations from the 0.5^o diameter solar disk and small part of the sky.

Hemispherical sky radiation or diffuse radiation can be measured by shading a pyranometer with a disk located to subtend the same angular field of view as a pyrheliometer.

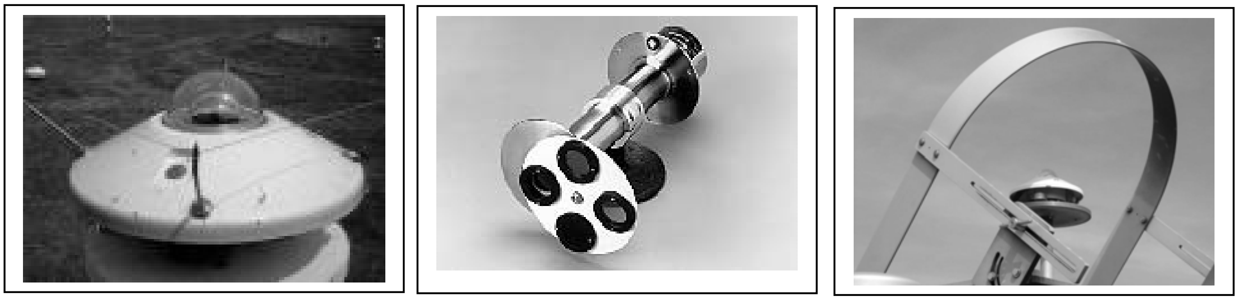
Further there are few schemes [5, 6] intended for online recording of solar radiation by means of data acquisition systems and PC. Difficulties of these schemes are necessity of custom built hardware and software and continuous engagement of the computer.

3. Simple Instrument for Solar Radiation Measurement

Sophisticated instruments such as pyranometer and pyrheliometer give accurate insolation measurement [7] but these instruments are not suitable for large scale use because of two main reasons:

- They are quite expensive and availability is not plenty.
- They can be handled only by technical persons with specialized knowledge.

This restricts the use of such instruments and thereby comes in the way of gathering sufficient amount of solar radiation data. Hence what are required are simple user friendly instruments operated by any educated person and affordable for multiple piece procurement. Such instruments may be less accurate. They may not show good sensitivity to the whole solar spectrum and thus could not be calibrated as accurately as a Pyranometer. But they can help in getting more amounts of data in term of time resolution, variation of site, various atmospheric and climatic conditions etc, which is much more useful for proper understanding of solar radiation data.



(a) Pyranometer (b) Pyrheliometer (c) Shaded Pyranometer

Figure 1: Standard Solar radiation measuring instruments.

Simple hands held solar radiation meters are available for this purpose that measures the intensity of global incident solar radiation (G) in watt/m^2. But they are mostly analog. So they suffer from typical limitations of analog meters like sluggishness of response, backlash error, error caused by non-horizontal position of resting, parallax error of reading etc. A simple digital insolation meter will be free from aforesaid limitations.

The basic requirement for insolation measurement is a suitable transducer, which can generate a voltage or current directly proportional to the available insolation intensity. The linearity of these transducing characteristics controls the level of accuracy of the insolation meter.

Single Crystal Silicon Solar cell is a good choice for such transducer. Short Circuit Current of a single crystal silicon solar cell (I_{SC}) changes linearly with change in insolation level, as shown in Figure 2.

It is well known that two essential parameters of a solar cell are open circuit voltage (V_{OC}) and short circuit current (I_{SC}). The optically generated current in solar cell is [8].

$$I_{op} = q \times A \times g_{op} \left(L_p + L_n + W \right) \quad (2)$$

where, g_{op} = Electron hole pair generation rate (EHP/cm^2)

L_p = diffusion length of p side.

L_n = diffusion length of n side.

W = Depletion region.

A = Area of the junction.

It is interesting to note that the aforesaid optical current can be obtained by short circuiting the two terminals of the solar cell even when it has no biasing voltage. Equation (2) shows that short circuit current of solar cell I_{SC} is proportional to the generation rate. Generation rate being directly proportional to the light intensity, the short circuit current of a single crystal silicon solar cell becomes a linear function of insolation intensity.

Mathematically,

$$I_{SC} = k \times \textit{Insolation Intensity} \quad (3)$$

Where k is a constant and represents the sensitivity of the silicon solar cell in units of mA-m^2/ W.

This phenomenon is used for fabricating a digital insolation meter.

4. Fabrication and Technical Specifications

The block diagram of the digital meter is shown in Figure 3. In the block diagram given in Figure 3, the short circuit current through the solar cell is converted to a proportional voltage across a small shunt resistance. Here the smallness of the resistance value is critical and if it goes above certain value so as to suppress the short circuit effect, the voltage across it does not remain linearly proportional to the insolation intensity level any further. Experimentally it has been established that with any value within 0.01Ω to 0.5Ω, the linearity of the change in current though the cell with respect to insolation level is well maintained. The voltage developed across the shunt resistance is applied to the input of a dual slope integrating A/D converter.

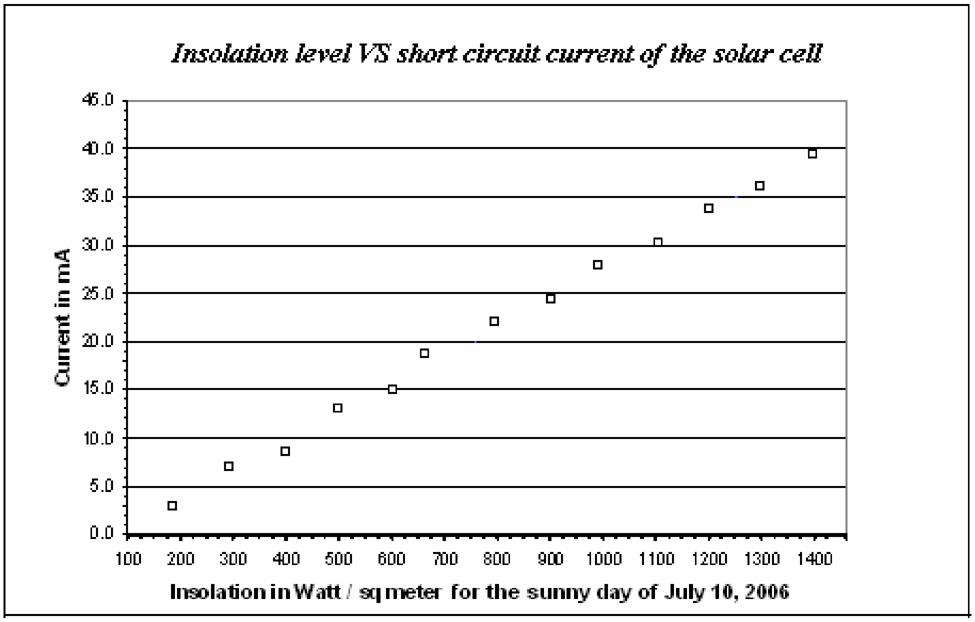


Figure 2: Relation between Intensity of Insolation and I_{sc} of a single crystal silicon solar cell.

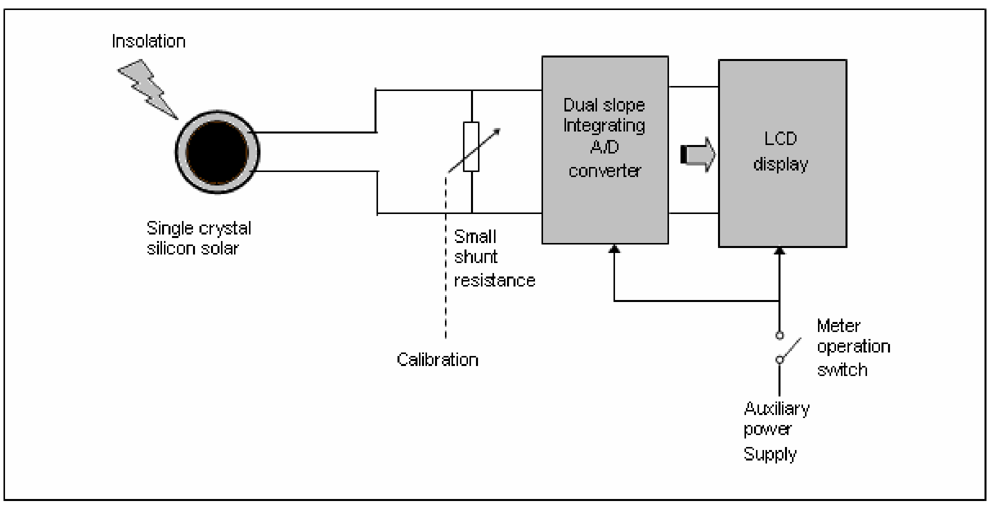


Figure 3: Block Diagram of the Digital Insolation Meter.

The digital output of the Analog to Digital Converter (A/D) can easily be read through a standard Liquid Crystal Display (LCD) circuit. In the prototype piece fabricated by the authors, these two blocks were substituted by a ready available digital milli-voltmeter. The voltmeter had following specifications:

- Input impedance: 100MΩ,
- Auxiliary supply: 9 (7-11) VDC,
- Display: 3-1/2 digits,
- Input range: 0 – 1999.9mV,
- Refreshing rate: 3 readings / sec,
- Polarity indication: disabled.

The insolation meter is powered up by a standard 9 volts dry cell and power consumption is of the same order of that of a digital multi-meter. As the meter is switched on, insolation measurement is carried out continuously with a display updating rate of 3 times per second. The resolution of measurement is 10 $Watt/m^2$.

5. Calibration and Performance Testing:

To start with, the value of the shunt resistance was so chosen in the permissible range, that the numerical value of the voltage (mV) generated across it is close to the numerical value of insolation intensity (kW/m^2). Theoretically this value was calculated to be 33mΩ.

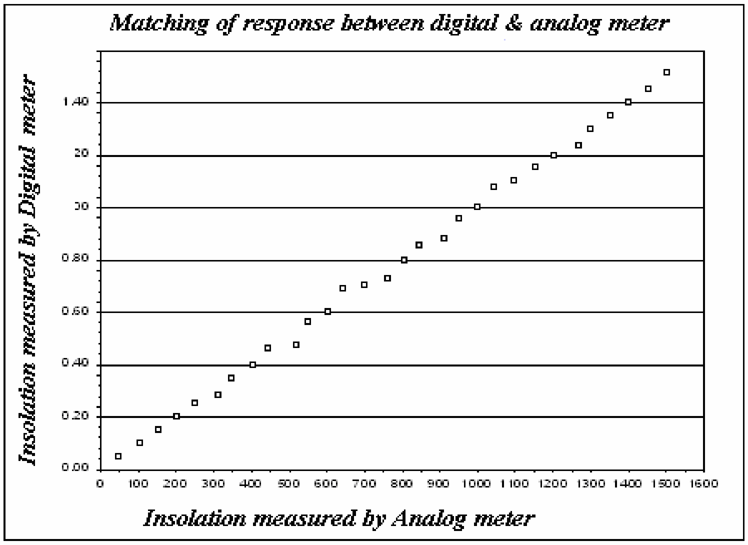


Figure 4: Laboratory matching of readings of the digital meter with a standard analog meter.

6. Conclusion

It is evident from the block diagram as shown in Fig.3, that this method of using a single crystal silicon solar cell in conjunction with a very low value precision resistance makes the scheme essentially a very simple one to fabricate. SPV cells continue to work with specified efficiency and accuracy for a life span of 20-25 years. Obvious difficulty in getting a small resistance of the order of 33 mΩ had to be solved by using a suitable parallel combination of commonly available low value resistors.

This digital insolation meter can be put to actual use in roof top or laboratory environment by just holding it in such a way that the sensor remains perpendicular to the incident radiation. There is no scale selection or zeroing requirement.

Thus by virtue of its simple construction and usability, this meter is expected to find wide spread application across solar industries, power stations, field engineers, academic scholars etc. Laboratories lacking high grade infrastructure can also use it for their solar data collection purpose.

7. References

[1] Weather Monitoring instruments and systems, *Nova Lynx Corporation Ltd*., Available: http:/www.novalynx.com/ products.

[2] D. R. Myers, "Solar radiation modeling and measurements for renewable energy applications: Data and model quality", in *International expert conference on mathematical modeling of solar radiation*, Edinburgh, Scotland, September 2005.

[3] J.A Duffie, and J. Beckman, "Solar Engineering of Thermal Processes". *John Wiley and Sons*, *New York* W.A.1980.

[4] S. P. Sukhatme,."Solar energy: principle of thermal collection and storage", *TMH, 2003* edition.

[5] D. Mukherjee, A. Roy, "Design of a simple data acquisition system for online recording of solar radiation", in *National solar energy convention*, 1998 (SESI), Roorkee, Dec 1998, pp. 226-230.

[6] K. Somasundaram, "A PC based solar radiation measuring system", *Journal of the solar energy society of India*, 2001.Vol. 16, No. 2.

[7] K. Somasundaram, "Microcontroller based solar radiation measuring instrument", *Journal of the solar energy society of India*, Vol. 16, No. 1, pp.15-21.

[8] M. S. Kaiser, S K Aditya, R K Mazumder, "Performance evaluation of a solar module using computer aided ray tracing technique", *International Conference on Renewable Energy*, February 27-28, Dhaka, Bangladesh. 2004, pp. 23-26.

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