APPLICATION OF DIGITAL MULTIMETER IN THE MEASUREMENT OF SOLAR RADIATION INTENSITY

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Abstract: A microchip solar cell connected to a digital multimeter was applied in the measurement of solar radiation intensity (SRI). The calibration was carried out for thirteen weeks by placing the modified digital multimeter side by side a Standard Solarimeter at NIMET observatory station located in Umudike, Abia state, Nigeria. The calibration produced a conversion factor [Digital Multimeter reading = $0.0112(SRI\ )$+ 1.723] to correlate the voltage readings of the digital multimeter to a Standard Solarimeter. Values obtained by the digital multimeter were converted to watt per meter squared by the use of the conversion factor. The coefficient of determination (R^2) from the correlation gave 0.91525 which signifies strong relationship the between measure voltage and measure SRI. The study concluded that the modified digital multimeter could be used to measure global solar radiation intensity of any location with relative high accuracy. Results from the measurement suggest that Umudike, Abia state belongs to high solar radiation zone of the globe this level of solar radiation/in solation will support any solar energy projects.
Keywords: Solar radiation, digital multimeter, solar cell, solarimeter, Umudike

Introduction

Solar radiation intensity is a measure of the level of electromagnetic radiations which are received from the Sun to the Earth. It varies from one point on the Earth surface to another (Chineke, 2007). Solar radiations consist of rays of radiant energy and Electromagnetic waves of various wavelengths. The quality and intensity of solar radiations change considerably on its journey through the earth's atmosphere. Solar radiation intensity is measured in Watts per square meter (W/m^2). The Total Solar Irradiance (TSI) upon the Earth was earlier measured by satellite to be roughly 1.366 Kilowatts per meter square (Kopp *et al*, 2005). Solar Radiation could be measured as Global solar radiation, Direct Solar Radiation or Diffuse Solar Radiation (Gairaa and Bakelli, 2011; Trabea, 2000).

Donald (1982) noted that the quantity of solar radiant energy available at a location is known as Solar Radiation Intensity. Solar radiation intensity is the amount of solar energy that is incident on the earth's surface per unit area per day. It is usually expressed in $kWhm^{-2}$ per day or MJm^{-2} per day.Solar radiation is important in Agriculture, for crop drying, electricity generation, house heating, water pumping for irrigation, etc. In solation figure of a location is usually necessary before selecting a site for photovoltaic and other solar energy projects (Asiegbu, 2013).

Solar radiation allows life to flourish; it determines the rate of photosynthesis in plants and strongly regulates the amount of evaporation from rivers and streams. It warms the planet and gives us our everyday wind and weather. Without solar radiation the earth would gradually cool in time, becoming encased in layer of ice (Brooks and Minis 2000).

Chineke (2007), Chiamaka (2009), Asiegbu and Nduka (2006) observed that the number of stations measuring solar radiation are sparse in Nigeria. Only few stations have been measuring the daily solar radiation intensity. This is due to unavailability of solar radiation measuring device like, Photometer, Solarimeter, Pyronometer, etc. Generally, most of these solar radiation measuring devices are expensive and this has led to scarcity of solar radiation data in areas and places where they are needed for example, Umudike, located between longitude 7.55^0E and Latitude 5.48^0N. Considering the high and wide interest in the development of solar technology in Umudike and its environs, the Utilization of solar radiation in the construction of solar dryers, solar heaters etc and the effect of solar radiation to human existence, there is urgent need to have a portable, less expensive solar measuring device for the monitoring of systematic fluctuations of solar radiation intensity with respect to a given location. Recently, some researchers have made efforts to develop alternative solar radiation measuring devices (Asiegbu and Nduka, 2006; Workman and Mark, 2013). Most of these measuring devices have different limitations such as availability, accuracy and high cost. Therefore, this study is designed to produce a readily available low-cost instrument with ability to measure solar radiation intensity with very high degree of accuracy.

Materials and Methods

A rectangular micro solar cell (4 cm by 2 cm) placed on circular disc of diameter 12 cm was connected to a digital multimeter (model DT830D). The circular disc (panel) was mounted on a tripod stand 1.5 m above the ground level in an open field. The in-built inclinometer of the tripod stand was used to incline the cell at the angle of the latitude of Umudike which is about 5^0 N, (Chiemeka 2008; Asiegbu and Nduka, 2006). Such adjustment is usually critical for finding maximum solar radiation intensity of a location (Asiegbu 2013; Eke 2011). An open field was selected to avoid obstacles blocking or affecting the experiment. This was based on avoiding obstacles in the easterly and westerly directions (Bamiro, 1981). The positive and negative terminals of the solar cell were connected to the positive and negative terminals a digital multimeter through a low resistance USB cord. Since the cell is essentially a p–n junction diode, radiations falling on its surface produce electromotive force (EMF) which is proportional to the global solar radiation intensity on that location. Thus, the corresponding voltage value was read and recorded from the digital multimeter. The time and date of measurements were equally recorded.

For purposes of calibration, the device was placed beside a standard solarimeter (Dayster meter DS05A) at NIMET observatory station Umudike. Hence the transfer calibration method was used to compare the readings (Workman and Mark, 2013).

Results and Discussion

Measurements were done for thirteen weeks and the readings are shown in Table 1(a) and 1(b). Graphical representation and analysis of these data are shown in Figs. 1 – 3. Figure 1 is the graphical representation of measured voltage against time. Fig. 2 is the graph of SRI against time while Fig. 3 is the graph of measured voltage against SRI.

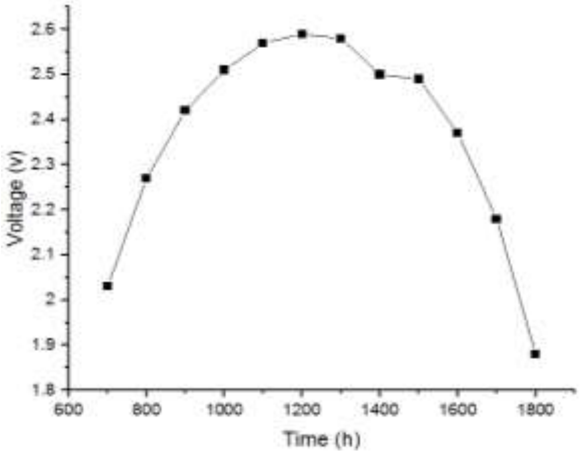

Fig. 1: Variation of voltage against time

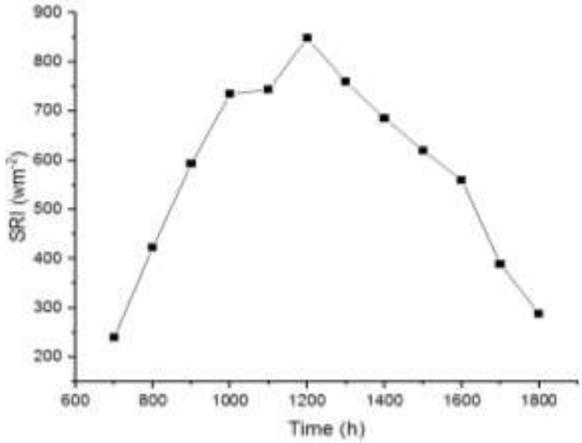

Fig. 2: Variation of SRI against time

From the results on Tables 1(a) and (b) it would be observed that the values obtained from the standard device were in higher multiple when compared to the values from the digital multimeter. These values increased until between 1200 or 1300 h when they start decreasing.

From the values obtained from the final average readings of Table 1(b) three variables could be observed;

a) time of observation in h
b) voltage (Ave voltage) in (Volt) from the multimeter
c) solar radiation intensity (SRI) in W/m^2 from the standard solarimeter

Table 1a: Hourly result of voltage and SRI for thirteen weeks

S/N	Time (h)	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7		Week 8		Week 9	
		Voltage (v)	SRI (/m^2)	voltage (v)	SRI (w/m^2)	Voltage (v)	SRI (w/m^2)	Voltage (v)	SRI(w/m^2)	Voltage (v)	SRI (w/m^2)	Voltage (v)	SRI (w/m^2)	voltage (v)	SRI (w/m^2)	Voltage (v)	SRI (w/m^2)	Voltage (v)	SRI (w/m^2)
1	700	2.01	230.9	1.99	176.1	1.97	205.0	2.09	273.5	2.06	219.0	2.05	228.0	2.05	216.5	2.00	225.7	2.05	218.5
2	800	2.25	453.2	2.28	472.2	2.36	384.5	2.30	406.6	2.22	505.6	2.26	456.7	2.30	505.5	2.24	443.9	2.28	486.9
3	900	2.42	605.6	2.42	506.3	2.44	606.1	2.43	586.0	2.42	615.0	2.43	635.7	2.42	608.5	2.41	613.9	2.42	608.9
4	1000	2.53	744.6	2.51	767.1	2.53	786.4	2.54	567.0	2.48	787.9	2.55	820.8	2.55	667.0	2.54	778.2	2.54	779.6
5	1100	2.55	795.1	2.55	784.1	2.56	805.7	2.60	794.0	2.54	819.1	2.63	908.8	2.61	819.5	2.57	822.7	2.60	816.4
6	1200	2.56	802.6	2.56	790.5	2.57	806.1	2.65	800.7	2.56	954.2	2.68	991.2	2.65	974.9	2.59	814.4	2.62	194.9
7	1300	2.53	791.3	2.52	761.7	2.49	588.6	2.64	794.8	2.55	797.5	2.67	990.9	2.68	993.3	2.59	814.4	2.63	198.6
8	1400	2.47	645.2	2.45	608.9	2.27	616.4	2.60	761.8	2.51	867.9	2.63	922.6	2.64	946.8	2.50	707.1	2.58	825.1
9	1500	2.43	615.8	2.40	592.7	2.39	574.7	2.52	675.3	2.52	813.6	2.56	808.2	2.55	817.4	2.45	641.1	2.69	606.8
10	1600	2.37	569.0	2.30	399.0	2.23	433.8	2.43	641.6	2.44	639.4	2.45	674.7	2.42	632.5	2.40	603	2.40	598.7
11	1700	2.00	250.6	2.03	277.8	1.99	241.3	2.26	529.7	2.33	440.4	2.29	506.0	2.49	472.1	1.99	229.2	2.15	356.2
12	1800	2.85	200.9	1.87	204.6	1.79	128.5	2.14	380.6	2.18	314.0	2.16	352.6	2.16	356.1	1.85	193.6	1.99	266.2

Table 1b: Hourly result of voltage and SRI for thirteen weeks

S/N	Time (h)	Week 10		Week 11		Week 12		Week 13		Final results			
		Voltage (v)	SRI (/m^2)	Voltage(v)	SRI (w/m^2)	Voltage(v)	SRI (w/m^2)	Voltage(v)	Voltage(v)	Total value Voltage (v)	Total value SRI (w/m^2)	Average voltage (v)	Average SRI (w/m^2)
1	700	2.08	313.5	2.02	238.7	2.00	241.9	2.10	273.4	26.42	3126.7	2.03	240.5
2	800	2.28	500.1	2.22	408.0	2.24	401.9	2.28	476.6	29.5	5501.7	2.27	423.2
3	900	2.37	557.5	2.38	536.8	2.42	600.0	2.14	589.3	31.46	7710.2	2.42	593.1
4	1000	2.53	760.0	2.45	639.4	2.49	714.2	2.49	712.3	32.68	9549.5	2.51	734.6
5	1100	2.58	797.5	2.49	737.6	2.55	776.4	2.45	687.6	33.41	9664.5	2.57	743.4
6	1200	2.57	806.1	2.57	807.1	2.60	849.2	2.48	714.6	33.61	11026.4	2.59	848.2
7	1300	2.53	775.7	2.59	741.1	2.57	816.2	2.50	616.4	33.49	9870.5	2.58	759.3
8	1400	2.50	765.7	2.50	722.8	2.48	709.0	2.42	554.9	32.55	8911.2	2.50	685.5
9	1500	2.48	717.8	2.44	531.4	2.45	628.5	2.36	534.5	32.37	8057.8	2.49	620.0
10	1600	2.39	556.9	2.36	534.3	2.37	562.6	2.28	425.7	30.84	7271.2	2.37	559.3
11	1700	2.30	542.9	2.23	374.7	2.23	430.0	2.20	403.8	28.29	5060.7	2.18	389.3
12	1800	2.24	448.5	2.07	299.2	2.04	273.4	2.10	323.6	24.44	3741.8	1.88	287.8

The curve of voltage against time and solar radiation intensity (SRI) against time; i.e. Figs. 1 and 2 are similar, voltage and SRI increased steadily up to 12000 and 1300 h before they started to decrease gradually. This shows that voltage produced over time increase with solar radiation intensity
Figure 3 is a simple linear regression analysis graph correlating SRI and Voltage. This produced a straight line graph whose equation gave the relationship between values obtained from the multimeter and values from the standard solarimeter, mounted at the NIMET observatory in National Root Crops Research Institute (NRCRI), Umudike, Abia State. The equation obtained from the graph by simple linear regression is used in the calibration and standardization of the constructed digital solar radiation meter;

$$y = mx + c$$

Digital Multimeter reading = $\mathbf{0.0112}(SRI)$ **+ 1.7231**

Where: SRI = Solar Radiation Intensity in Watt per meter squared (w/m^2); V= Voltage, as displayed by the digital solar radiation meter

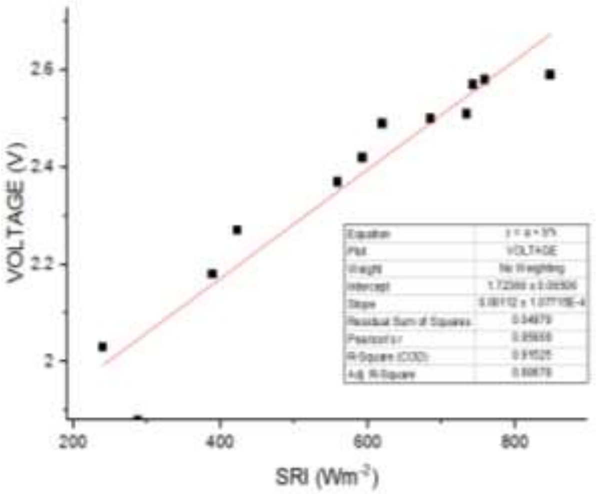

Fig 3: Simple linear regression analysis correlating SRI and voltage

The results obtained from the analysis showed a very good dependence and relationship between measured parameters. With the formula in Equation (1), any value obtained from the digital multimeter in voltage could easily be converted to solar radiation intensity in W/m^2. From the same graph also, it could be deduced that solar radiation intensity is directly proportional to voltage as obtained in the digital multimeter. From Figs. 1 and 2, it could be deduced that the active solar period in Umudike is between 800 to 1700 h and the maximum average of solar radiation intensity about 848.2 w/m^2, this is enough to support commercial agriculture as well as solar projects. The maximum solar radiation intensity occurs between 1000 to 1400 h. This implies that the optimum performance of any solar project/ demonstration in Umudike should be evaluated between these periods.

Conclusion

A microchip solar cell connected to a digital multimeter was used in the measurement of solar radiation intensity (SRI). The calibration was carried out for thirteen weeks by placing the modified digital multimeter side by side a standard solarimeter at NIMET observatory station located in Umudike, Abia state, Nigeria the calibration produced a conversion factor, to correlate the voltage readings of the digital multimeter to a Standard Solarimeter. The result of the calibration which was used as preliminary investigation of global solar radiation intensity suggests that Umudike belongs to the high radiation zone of the globe and the level of radiation supports solar energy projects. From the analysis the values obtained by the digital multimeter was converted to watt per meter squared by the use of the relationship. Digital Multimeter reading = $0.0112(SRI)$+ 1.723. The coefficient of determination (R^2) from Figure 3 which is 0.91525 gave a very good relationship the between measure voltage and SRI. From the data collected and the analysis made, the work and the result are in full agreement with already established facts and earlier measurements made in Umudike.

Conflict of Interest

Authors declare that there is no conflict of interest reported in this work.

References

Asiegbu AD & Nduka OA 2006. Determination of Solar Insolation in Michael Okpara University of Agriculture, Umudike, Using a Photo Resistor. *GJPAS*, 12(2): 245 – 250.

Asiegbu AD 2013. Preliminary investigation of solar insolation in Ihite Uboma LGA of Imo state,South East Nigeria – using a photoresistor arrangement. *Int. J. Current Res.*, 5(2): 013-016.

Bamiro OA 1981. Empirical relation for the determination of solar radiation in Ibadan. *Nigeria Solar Energy*, 31: 85 – 94.

Brooks D & Minis A 2000. Definition of Solar Radiation Intensity. New York McGraw Hill, p. 442.

Chiemeka IU 2008. Estimation of solar radiation at Uturu, Nigeria. *IJPS*, 3(5): 126-139.

Chineke TC 2007. Renewable Energy Equation for Estimating Global Solar Radiation Data Spare Regions Science Direct, pp. 1 – 13.

Donald CA 1982. Meteorology Today: An Introduction to Weather, Climate and The Environment. West Publishing Co., pp. 18-22.

Eke BA 2011. Predication of option angle of inclination for flat plate collector in Zaria. *CIGR Journal*, 13 (4):16 – 20.

Gairaa K & Bakelli Y 2011. An overview of global solar radiation measurements in Ghardaïa area, south Algeria. *Int. J. Energy and Envt.* (IJEE), 2(2): 255-260.

Kopp G, Lawrence G & Rottman G 2005. Solar irradiance and properties. *Science News Journal*, *Solar Physics*, 230: 129-140.

Trabea AA 2000. Analysis of solar radiation measurements at Al-Arish area, North Sinai. *Egypt Renewable Energy*, 20: 109-125.

Workman J & Mark H2013. Measuring the agreement between instrument following calibration transfer, 28(10): 24 -34.