Solar Irradiance Meter

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Abstract- **Solar cell is a semi conductor device that converts light into electrical current and voltage. The intensity of solar light is call Irradiance and it can be measure using a pyranometer. Currently, the available pyronometer in the market is expansive and not commercially availabe. The purpose of this project is to design and create a low cost solar irradiance (W/m2) meter using a solar cell. The solar cell produce short circuit current which is linearly proportional to irradiance. The function of this meter is to convert the short circuit current to voltage using a transimpedance amplifier. The result of the converted current will then be display to LCD display using microcontroller PIC16f873A. The voltage converted by amplifier is linearly proportional to the irradiance.**

Keyword: Solar Irradiance, Solar cell, Short Circuit Current, Transimpedance Amplifier

I. INTRODUCTION

Sunlight is part of the electromagnetic radiation generated by the sun, mainly infrared light, ultraviolet, and visible light. Sunlight is filtered through the Earth's atmosphere, and it is very clear when the sun is above the horizon. Meanwhile, sunshine is a combination of bright light and radiant heat which is produce when the direct solar radiation is not blocked by clouds. If the direct solar radiation is being blocked by the clouds, it is called as diffused light. Solar radiation is a term used to describe visible and near-visible (ultraviolet and near-infrared) radiation emitted from the sun.

Photovoltaic cell (PV) are semi conductor PN junction diode that can provide electrical power to a load. As illustrate in fig 1, using a PV cell, the sunlight can be converted into electric current and voltage using photovoltaic effect. Increasing the intensity of the light beam increases the number of photons in the light beam, and therefore increases the number of electrons excited. The current produce by the PV is called short circuit current, (Isc) while the voltage is called open circuit voltage, (Voc). The Isc flows with zero external resistant (short circuit) and is linearly proportional to the solar irradiance while Voc is the potential different develop between the terminal of the solar during large resistant (open circuit). The solar irradiance is defined as the intensity of solar power at point of observation which can be calculated using a pyranometer or solar irradiance meter.

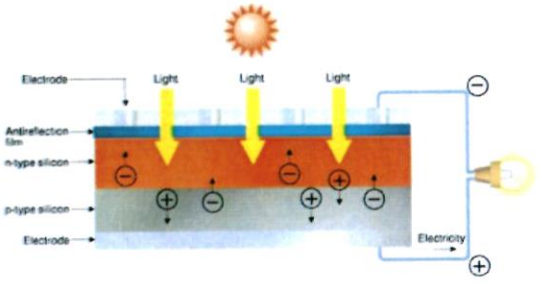


Figure 1: The basic solar cell structure

A pyranometer meter is a tool to measures instantaneous solar power and provides the reading in Watts per square meter ($W/m^{2)}$. The total power striking the PV cell can be calculated by multiplying the power with area of the PV cell. The pyranometer is basically a flat photodiode covered with a transparent dome that is coated with an extremely absorptive surface as illustrated in fig 2. As the sun strikes it, the surface gets hot. The temperature of the surface is measured with a thermopile, giving an output voltage related to the amount of solar radiation striking the surface.There are many types of pyronometer and the most of them use photodiode as the sensor to measure solar irradiance.



Figure 2: Pyranometer

Although solar irradiance meter is a necessary tools in the study of PV energy, they are expensive[3] and not commercially available. In Malaysia, they cost around hundred to thousand of Ringgit proportional to their high accuracy. Since PV system, large and small, is a growing industry in Malaysia, there are a lots of growing demand for inexpensive solar irradiance meter and this demands comes from contractor, university and even small consumer. Instead of buying the expensive solar irradiance meter, an alternative way is to create a low cost solar irradiance meter using a small monocvrystalline PV cell. This paper present a low cost

solar irradiance meter with reasonable accuracy at low price.

In fig.3 the block diagram of the system is presented. The signal which is the solar cell current are conditioned in order to be sensed by the Microcontroller. In the signal conditioning process, a transimpedance amplifier is used to isolate the current from the voltage and convert the input signal to a proportional output signal and transmitted it to the Microcontroller. By controlling the gain of such an amplifier, a small input current can produce a sizable output voltage for the Microcontoller. The Microcontroller will then do the calculation and display the irradiance value.

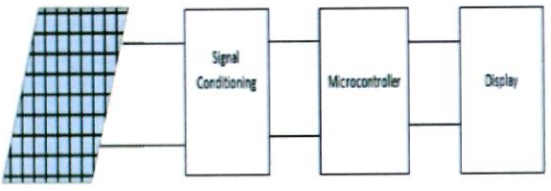


Figure 3: Block Diagram of The System

A. Objective

Below are the main objectives of this project:

a) To design and create a low cost solar irradiance meter.

b) To study the characteristic of solar cell; the relationship between short current and irradiance.

c) To test the accuracy of the design meter with existing solar meter

II. METHODOLOGY

Figure 4 shows the project procedure flow chart. There are 3 important parts in this project which is data collecting, circuit design and Microcontroller. A detail explanations of each process will be describe below.

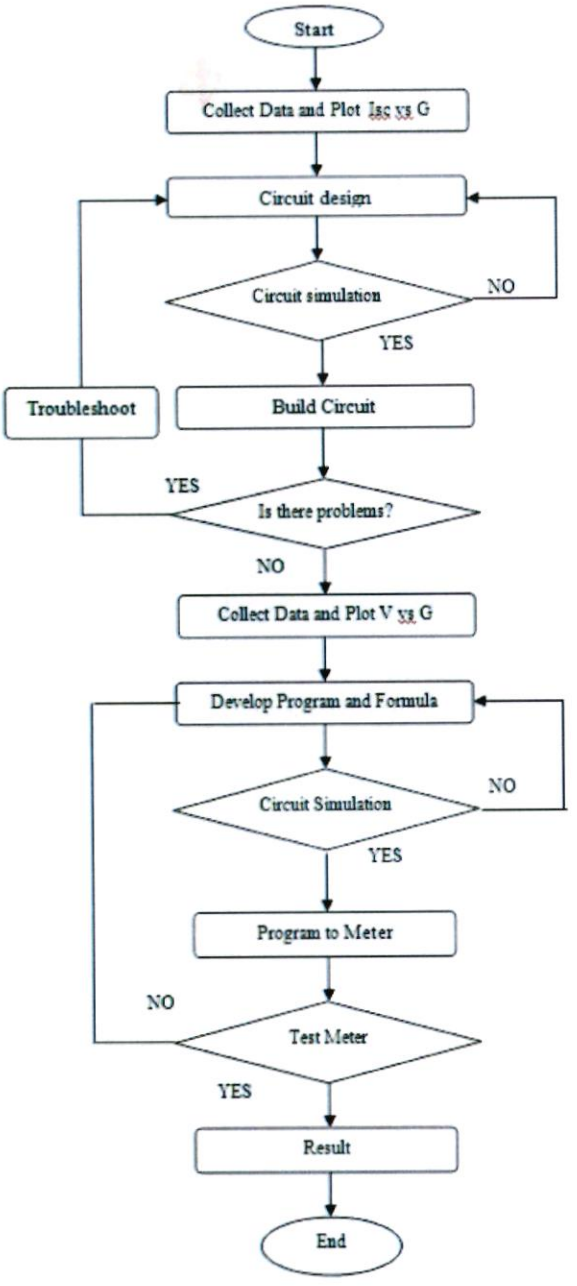


Figure 4: Project Flow Chart

A. Data Collecting

The first step of this project is collecting data from the solar cell. In this process, the current of the solar cell is measured using Multimeter, while a solar meter is used to measure the Irradiance, G. The purpose is to find the relationship between the Short Circuit Current and Solar Irradiance. Both data were taken at the same time and angle in a broad open space to avoid shading and inaccurate result. After collecting the data, a graph of Isc vs G was plotted. Fig. 5 shows an example of solar cell being calibrated.

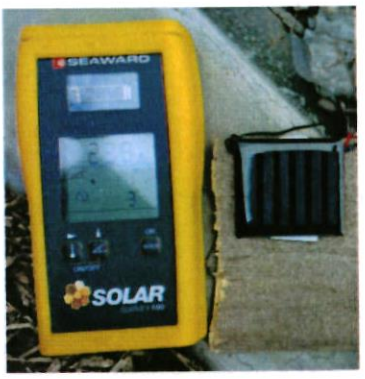


Figure 5: Calibrating Solar Cell

B. Circuit Design

The second step of this project is to design a circuit to convert the short circuit current to voltage. This step is also known as signal conditioning since the process involve ampliflying and converting the input current The short circuit current produce from the solar cell is between 0 to 60mA. In order to convert the current, a transimpedance amplifier is chosen since the characteristic of the amplifier which can even convert a micro current to a reasonable voltage output. This amplifier operates as a current to voltage converter due to its zero input and output impedance[7].

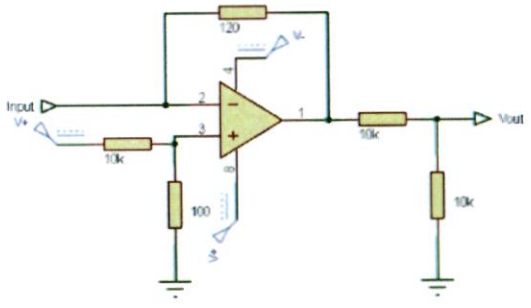


Figure 6: Transimpedance Amplifier

Figure 6 above shows the transimpedance amplifier circuit for this project. In order to design the circuit, there are 3 golden rules that must be follow.

1. No current ever flows into or out of the inputs.
2. Whatever voltage on one input will be the same on the other input.
3. If V_{out} is greater than the supply voltage then second rule will no longer applies.

The equation involve for calculating designing the op-amp:

$$Vout = IinRf \quad (1)$$

$$Rin = \frac{Vi}{Ii} = 0 \quad (2)$$

$$Atr = \frac{Vo}{Iin} = Rf \quad (3)$$

C. Microcontroller

A microcontroller is a device that can perform ADC, PVM and many more operation[4][5]. A 10-bit microcontroller, PIC16F873A is chosen for this project and Mikrobasic as the programming language. Flowchart of the microcontroller is illustrated at figure 7 below. The microcontroller process start by declaring all the variable involve and prepare to perform analog to digital converter.

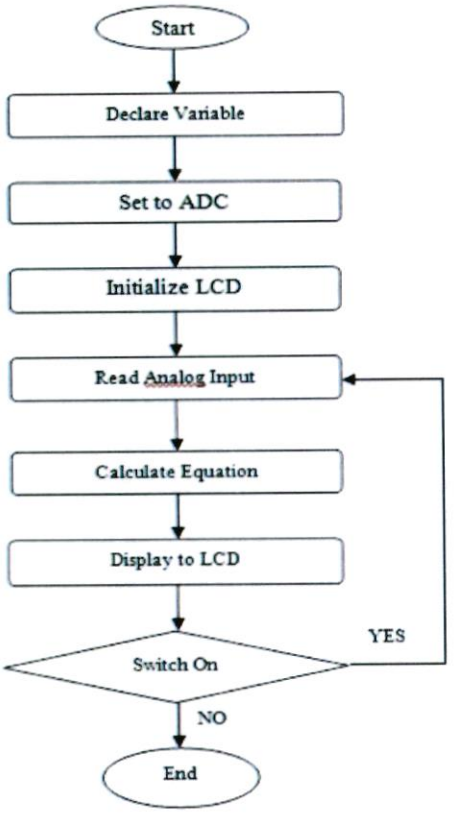


Figure 7: Program Flow Chart

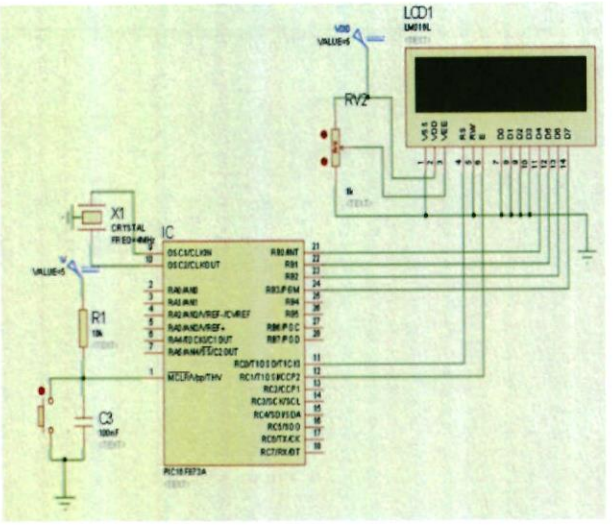


Figure 8: The PIC 16F873A connected to LCD Display

The output voltage of the transimpedance amplifier will be the input analog of microcontroller. The microcontroller reads the input and perform calculation based on the equation store inside the program. It will then display the output result to the display LCD. Figure 8 show the circuit for connecting LCD display to PIC16F873.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this section, 3 experiment was conducted to produce an accurate solar irradiance meter. The first experiment is to find the current characteristic of the solar cell. The next experiment is to determine the accuracy of the converter and the final experiment is to compare the performance of the meter.

A. Experiment 1:Relationship of Short Circuit Current Vs Irradiance

Table 1 shows a set of data obtain during calibrating the solar cell. From the data, as the current increases, the value of irradiance is also increasing. This shows that the short circuit current is linearly proportional to the irradiance.

I_{sc} (mA)	Irradiance (W/m^2)
52.2	922
49.6	873
43.3	776
36.2	650
27.7	538
26.3	442
21.6	364
14.5	262

Table 1 : Data of I_{sc} and Irradiance

To further support the linear relationship, a graph of I_{sc} vs G has been plotted as shown in figure 9. Based on the graph, it is proven that the short circuit is proportional to the irradiance and a linear equation can be obtain as shown below:

$$G = 17.95Isc - 7.517 \quad (4)$$

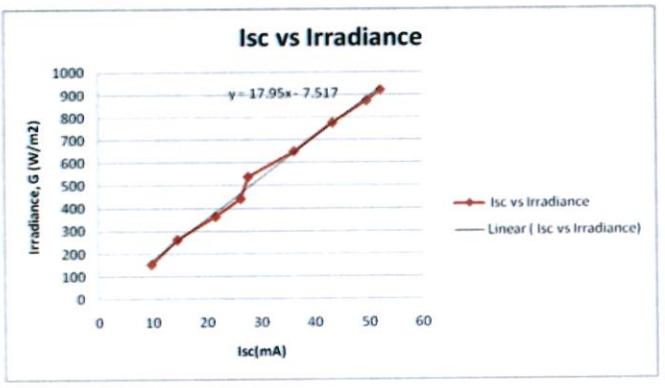


Figure 9 : I_{sc} vs Irradiance

B. Experiment 2:Relationship of Voltage Vs Irradiance

In this experiment, the output voltage from the transimpedance is measure to find out whether the output voltage is linearly proportional to the input current and solar irradiance. Since the converted voltage is based on the linear input current, the characteristic of the voltage must also be linear to the irradiance. If voltage increase, current will also increases. Table 2 shows a set of data obtain from the experiment.

Voltage (V)	Irradiance (W/m^2)
1.97	576
1.56	442
1.36	390
1.25	366
1.02	256
0.94	241
0.78	152
0.61	130

Table 2 : Data of Voltage and Irradiance

Based on the result obtain, a graph of Voltage vs Irradiance has been plotted as shown in figure. 10. Analysis from the graph shows that when the voltage increase, the irradiance is also increase. This proves that the voltage has been successfully converted and it is proportional to the irradiance. Therefore, the output voltage is proportional to the irradiance and a linear equation can be extract from the graph to be used for the Microcontroller. The equation is shown below:

$$G = 341.5V - 86.05 \quad (5)$$

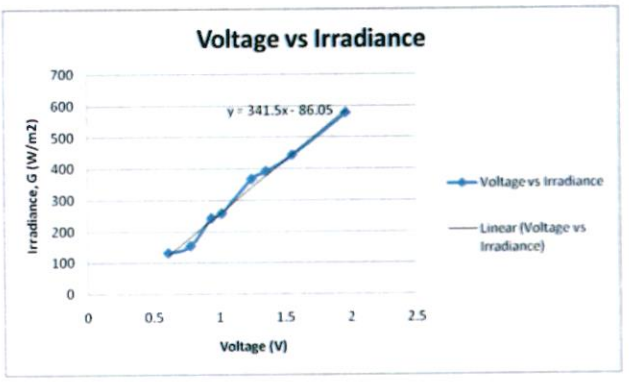


Figure 10 : Irradiance and Voltage Relationship

C. *Experiment 3: Comparing Design Meter With Existing Meter*



Figure 11 : Comparing the Solar Meter

The purpose of this experiment is to compare the designed meter with existing hand meter as shown in figure 11. Nine sample of design meter and hand meter data were taken at the same time and angle. The percentage of error is then calculated. The result of the data is display at table 3 below.

Irradiance (W/m2)			Percentage of Error (%)
No.	Designed Meter	Solar Meter	
1	262	255	2.67
2	264	256	3.03
3	314	306	2.55
4	434	422	2.76
5	517	528	2.13
6	643	623	3.11
7	730	710	2.74
8	740	725	2.03

Table 3 : System Performance Comparison.

By comparing the data in table 3, there is only a slight difference between the design meter and the solar meter. The highest percentage error produce by the designed meter is 3.11% while the lowest is only 2.03%. The error produce is maybe cause by human error which cannot be avoided. But since the range of error is only ±3, the designed meter is consider successful. To further prove the performance, a graph of design meter vs solar meter is plotted in Figure 12.

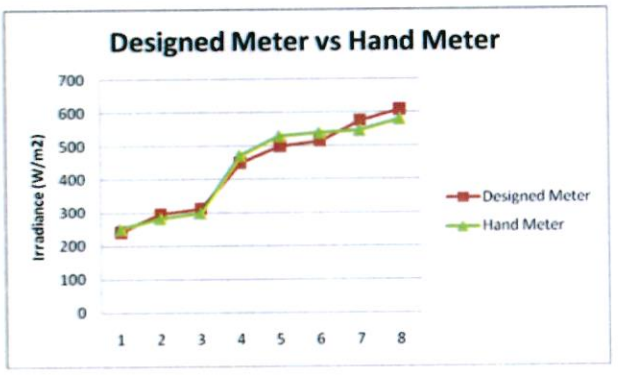


Figure 12 : Existing Irradiance Meter versus Designed Irradiance Meter

From the plotted graph, there is only a slight difference in the curve which will not affect the performance of the meter. By calculating all the material cost to produce this device, the cost is a lot much more cheaper than conventional solar irradiance meter. The price paid for the design meter is worth it for its performance.

IV. CONCLUSION

Based on the result on experiment, the linear relationship between current and irradiance has been prove. The Voltage produce is proportional to the input current. Furthermore, the error produce by the meter is accurate since it only produce ±5 % error which is within an acceptable range. The cost for producing the meter is much more cheaper than conventional solar meter. In conclusion, the objective of this project has been successfully achieve. The design meter has been produce a reading proportional to the solar irradiance with low cost and reasonable error .

To further improve the performance of the meter, a higher bit resolution such as a 16 bit microcontroller can be use. With higher resolution, the sensitivity of ADC will also increase producing more accurate result. Besides that, a temperature sensor can also be implement inside the design meter to monitor the solar cell and the environment temperature.

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V. REFERENCES

[1] D.L. King, W.E. Boyson, B.R. Hansen, and W.I. Bower. "Improved Accuracy For Low Cost Solar Irradiance Sensor", 2nd World Converence and Exhibition on Photovoltaiv Solar Energy Conversion.

[2] Cruz-Colon, J. ; Martinez-Mitjans, L. ; Ortiz-Rivera, E.I. "Design of a low cost irradiance meter using a photovoltaic panel ", Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE

[3] M. Shamim Kaiser, A.K.M. Fazlul Haque, M. Arifur Rahman, Abu Md. Zafor Alam, M. Mostafizur Rahman and S.L. Aditya " Lowcost Digital Solar Insolation Meter", Daffodil International University Journal of Scince and Technology.

[4] Microchip PIC16F873A Microcontroller, datasheet from"http://www.microchip.com/wwwproducts/devices.apx?ddocname=en010235
[7] E.C. Kern,M.C. Russell, "Rotating Shadow Band Pyranometer

[5] Lawrence A.Duarte. "*The Microcontroller Beginner's Handbook*".2nd Edition. United States of America: Promt Publication. 3-5; 1998

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

[7] Kossel, M., Nenolti C., Mod, T., et al, (2004) "A low-power 20-GHZ 52-dB transimpedant amplfier", IEEE journal, Solid -State Circuit.