A Portable Solar Irradiance Meter

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Abstract- **This paper presents a method of measuring the solar irradiance called a Portable Solar Irradiance Meter. The proposed technique helps to design simple, complex and low cost equipment. Same like other meter, this technique also have a same function which is to measure the solar irradiance in W/m^2. Due to the factor of cost of the sensor, a Portable Solar Irradiance Meter using microcontroller PIC 16F877A is designed. Instead of using other equipments such as sunshine recorder, pyranometer and pyrheliometer, a portable solar irradiance meter will also have the same functions with a low cost and simpler. On this project, a solar cell is used as a sensor to generate electric power where the energy from the sun will be converted into a flow of electrons. The solar cell is then been connected to auxiliary circuit as to amplify the current drawn from solar cell and to convert its current into voltage. All the analog output from auxiliary circuit become as input to microcontroller. PIC 16F877A was used in this project as to process all the output from solar cell before send it to information window (display). The information window is available to display the solar irradiance in W/m^2. Based on the result, the Designed Meter successfully measures the solar irradiance in W/m^2. All the data obtained from this project been tabulated in performance comparison table as to compared with Megger Meter and shows very low error at below 12%. From the system performance graph, it is clearly shows that the system designed almost has similarity with Megger Meter in irradiance measurement. Through this project, it can be concluded that the data produced is varies and reliable.**

Keyword: Solar irradiance, radiation, solar cell

I. INTRODUCTION

Solar energy is the most abundant renewable resource. The electromagnetic waves emitted by the sun are referred to as solar radiation. The amount of sunlight received by any surface on earth will depend on several factors including; geographical location, time of the day, season, local landscape and local weather. The light's angle of incidence on a given surface will depend on the orientation since the Earth's surface is round and the intensity will depend on the distance that the light has to travel to reach the respective surface. The solar irradiance received by a surface will have two components one which is direct and will depend on the distance the rays travel (air mass). The other component is called difuse radiation and is illustrated in figure 1[1]. There is a distinction between direct and diffuse radiation. When it comes directly from the sun it is known as direct radiation. When the radiation is scattered by the atmo- sphere back to Earth it is called diffuse radiation [2].

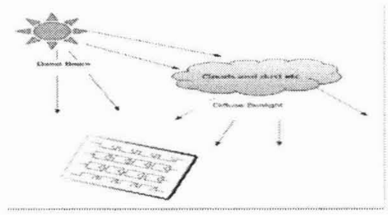

Figure 1: Types of radiation from the sun

When passing through the atmosphere, the solar radiation diminishes intensity because it is partially reflected and absorbed (above all by the water vapor and by the other atmosphereis gases). The radiation which passes through is partially diffused by the air and by the solid particles suspended in the air, as illustrated in figure 2.

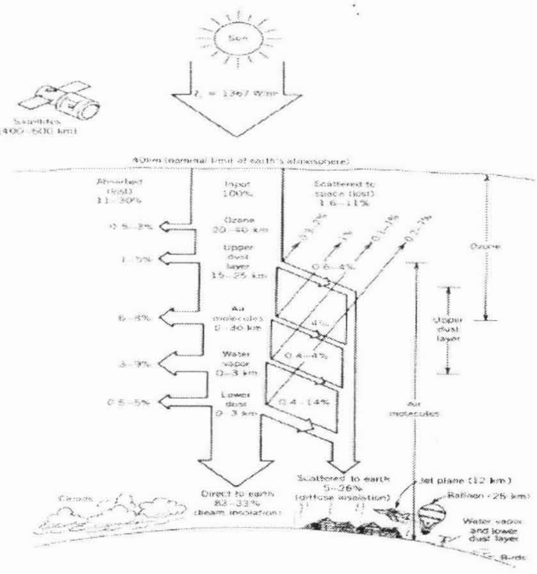

Figure 2 : Nominal range of clear sky absorption and scattering of incident solar energy

The energy comes from the sun to the Earth is in the form of Radiation. The amount of energy in the sunlight reaching the Earth surface is equivalent to around 10,000 times of the world's energy requirements [3]. The radiation received by solar cell surface or called solar irradiance can be measured by using a Solar Irradiance Meter. There are various types of meters are on the market at present such as Megger Meter. Price for the existing meters are quite expensive to acquire. Therefore, this project has been made to produce affordable meter with lower cost compared with the existing meters.

II. OBJECTIVES OF THE PROJECT

Following were main objectives of the project:

1. To design and develop a portable solar irradiance meter.
2. To develop a new control using microcontroller PIC 16F877A
3. To compare and validate system performance

III. MATERIAL AND METHODOLOGY

The research methodology flow chart is shown in Figure 3. It was started with hardware development and followed by software development.

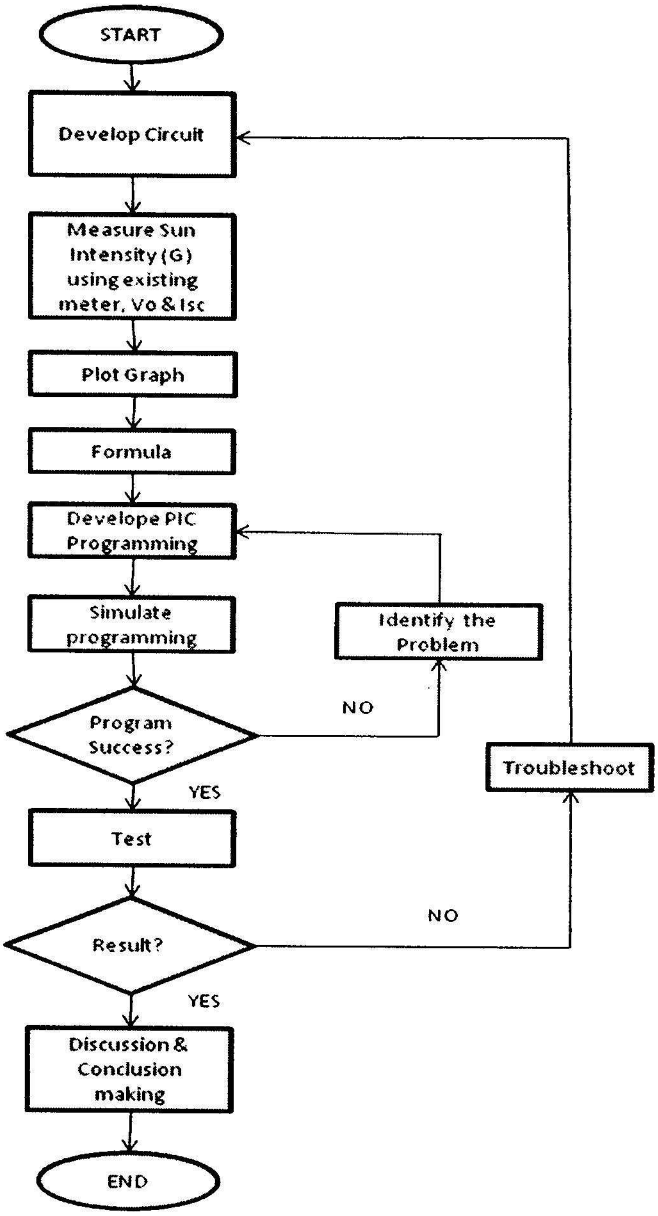

Figure 3: Research Methodology Flow Chart

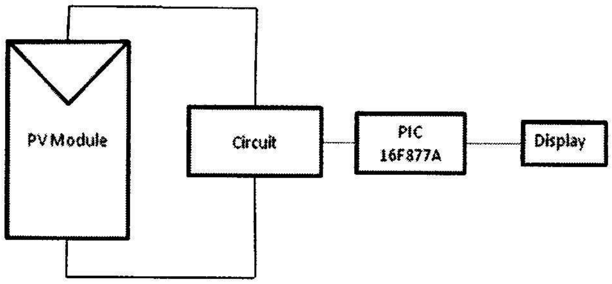

Figure 4: Block Diagram

In software development, the CCS PIC together with C Compiler was used in this project in order to control each of the components used in this project. For hardware development, several electronics components were used to achieve the project's objectives. The Portable Solar Irradiance Meter that was created consists of 5 segments:

1. Solar cell as an important part that receives the sunlight.
2. Auxiliary circuit – to amplify the current.
3. Current sensor connection – to convert the current to voltage before send to microcontroller
4. Processing segment which include PIC16F877A
5. LCD Display as an output segment.

Figure 4 shows the block diagram of the system designed that consists of 5 segments as mentioned above. All input from solar cell goes through the circuit and the next signal is sent directly to microcontroller for processing before displaying the results measured.

A. Solar Cell Calibration

The solar cell is calibrated with the existing meter (type Megger) and pyranometer sensor. Two quantities were identified which Short Circuit Current (I_{sc}) from the solar cell and Irradiance (G) from the Megger Meter. With two meters above (Ampere meter and Megger meter), two quantities were recorded simultaneously. Figure 5 shows how the solar cell being calibrated with Megger meter. Both meters and solar cell must be placed at the same angle and place to get accurate reading during calibration.

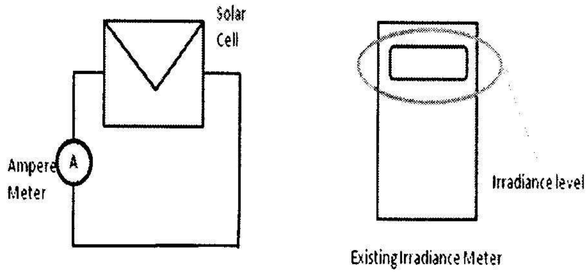

Figure 5: Calibration Method

The reason why both readings were measured is to get the relationship of these two parameters as changes in irradiance significantly affect the current of a PV device, but only have a much smaller effect on the voltage. Figure 6 illustrate clearly effect of the current and voltage when the change in irradiance.

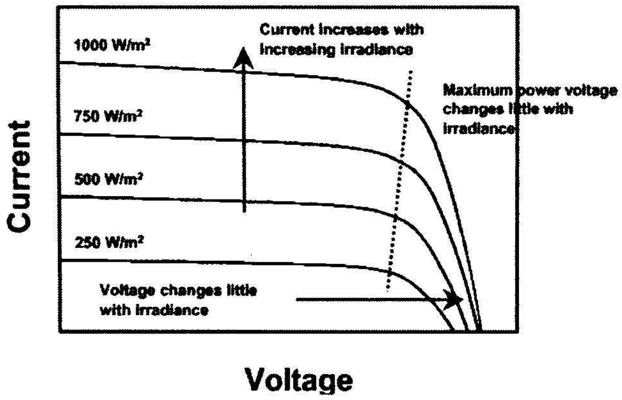

Figure 6: I-V curve – response to solar irradiance for typical PV module [4]

B. Circuit Development

The output current from the solar was too small. From the experiment, the highest output current at high irradiance is only 10.78 mA and causing no change of the current sensor output which is only at 2.5V. In order to overcome this problem and to increase the current produced by the solar cell, an auxiliary circuit has been produced using basic electronic components.

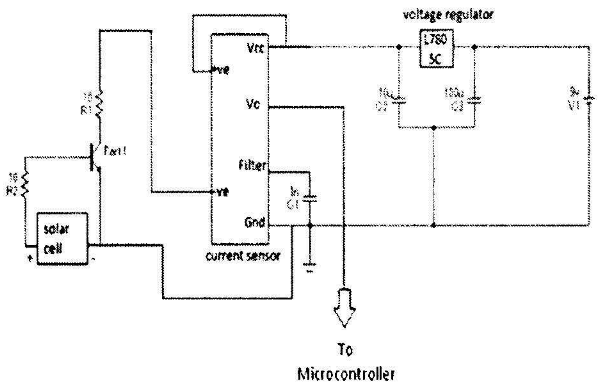

Figure 7: Auxiliary Circuit

Transistor being used in this circuit as to amplify the current drawn from the solar cell and current sensor is then converting the current flow into voltage as shown in figure 7. The current are successfully amplified. The voltage sensor here is useful in order to generate the formula by plotting the graph in relation with irradiance.

C. PIC Microcontroller

Microcontroller provides a user interface, sequence operations, and response to changing input [5]. The output from the current sensor will be connected to microcontroller. A program that consists of formula gain from experiments is programmed in thi microcontroller. Figure 8 shows a program flow chart.

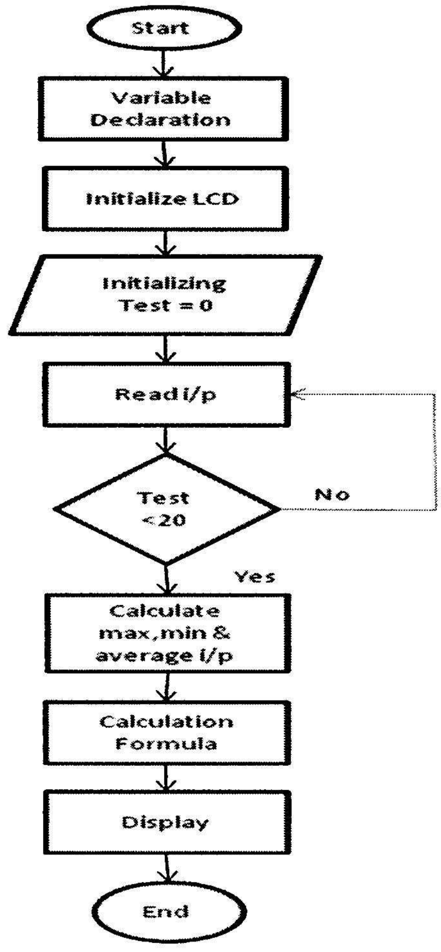

Figure 8: Program Flow Chart

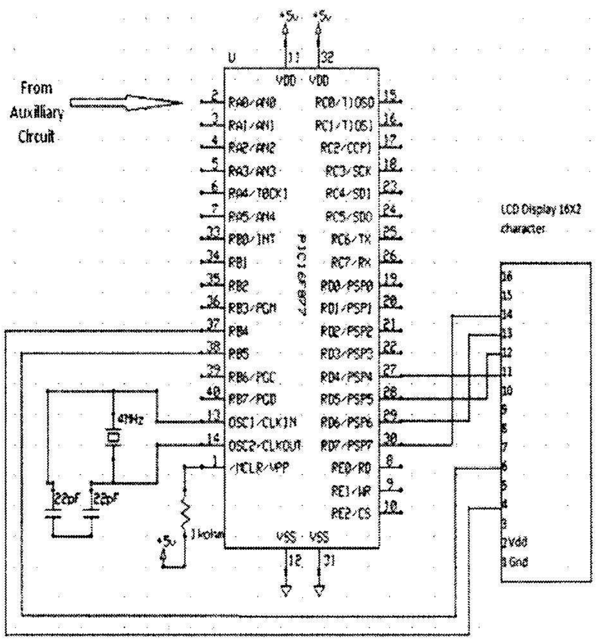

Figure 9: The PIC 16F877A connection with LCD Display

LCD display connected from microcontroller unit will display the irradiance and voltage level of the solar cell. Figure 9 shows the connection from auxiliary circuit and LCD display.

IV. RESULTS AND DISCUSSIONS

Several experiments have been carried out to achieve the objective set. First and foremost, an experiment is conducted to find out the relationship between the short circuit current of the solar cell and the irradiance. Later, the experiment of the circuit used was performed to identify the relationship between irradiance and voltage and thus obtain a formula which will be used in programming. Last but not least, from experiments conducted, all data and results were recorded for the purpose of comparing it with the existing meter.

A. EXPERIMENT 1: RELATIONSHIP OF SHORT CIRCUIT CURRENT AND IRRADIANCE.

An experiment is conducted to determine the relationship between the short circuit current of the solar cell and the irradiance. Three items were used in this experiment which is solar cell, multimeter and existing meter. As the result from this experiment, two parameters were obtained which is Short Circuit Current (I_{sc}) and Irradiance (G).

Isc(mA)	G(W/m2)
2.06	325
3.28	385
5.09	571
5.8	636
7.09	787
7.92	883
7.98	897
10.78	1225

Table 1 : Experiment Data of I_{sc} and Irradiance

From data collected shows in table 1, it is proven that short circuit current have linear relationship with irradiance as increasing of short circuit will result increasing of irradiance as well.

Figure 10 shows the graph of short circuit current and irradiance. From the graph, a formula has been generated such as equation (1).

$$G = 105.2\, I_{sc} + 55.67 \quad (1)$$

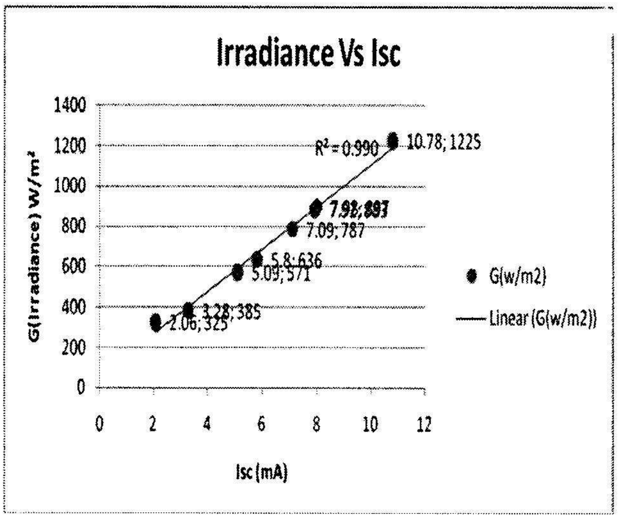

Figure 10 : Irradiance and I_{sc} relationship

It shows that the short circuit current varies with the irradiance and proved that short circuit current of the solar cell have a linear relationship with the irradiance. It can be said that the higher the irradiance, the higher the short circuit current.

B. EXPERIMENT 2: RELATIONSHIP OF VOLTAGE AND IRRADIANCE, AND FORMULA IDENTIFICATION.

The second experiment is conducted to determine the relationship between the short circuit current in term of voltage and the irradiance. Here, the complete system has been used. The voltages are measured at the output of the current sensor which originally was the amplified short circuit current of the solar cell. The amplified short circuit current been converted into voltage by the current sensor. The irradiance again was measured by using existing irradiance meter and the short circuit current was measured from solar cell connected with auxiliary circuit. This experiment also will also detect the voltage level of irradiance read by the existing irradiance. Figure 11 shows how this experiment was conducted.

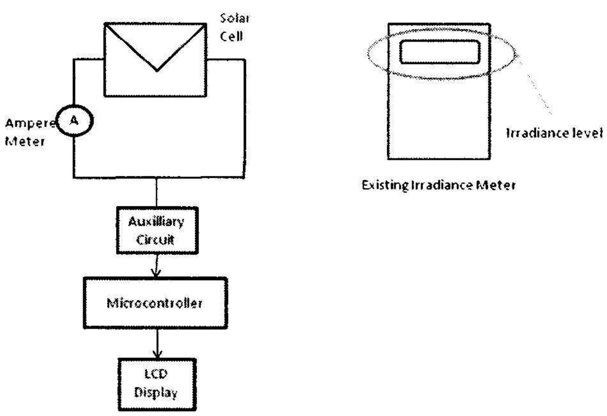

Figure 11 : Experiment with Complete System and Existing Meter

From the experiment as shown in figure 11, all useful data were recorded and only two parameters will be used for graph plotting in order to generate the formula which is amplified current from complete system and the irradiance from existing irradiance meter.

Isc(mA)	Voltage(mV)	G
64	12	325
121	22	342
183	34	471
231	43	536
273	51	636
338	63	661
418	78	883
562	105	931
602	113	1017

Table 2 : Data of Experiment 2

From the result from table 2, a graph has been generated. It is again shows that the short circuit current varies with the irradiance and proved that short circuit current of the solar cell have a linear relationship with the irradiance. Figure 12 shows the relationship of amplified current and irradiance.

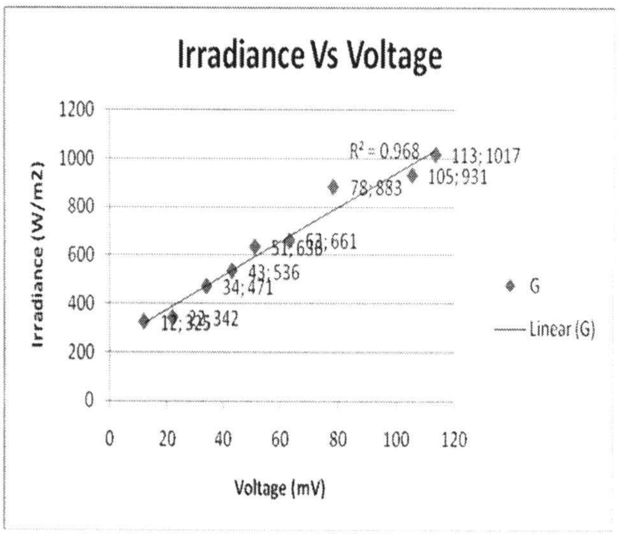

Figure 12 : Irradiance and Voltage Relationship

From that, a formula has been generated to be used in programming such as equation (2).

$$G = 70\,V + 179 \quad W/m^2 \qquad (2)$$

Here, the variation of short circuit current in term of voltage have resulted the variation of irradiance. This shows that the output of this system is reliable.

C. EXPERIMENT 3: COMPARISON OF PERFORMANCE

The final stage is the stage at which to determine whether the project was successful in meeting the objectives set. From the data collected from experiment 1 and 2, this project has been successfully implemented. Total of nine samples of irradiance were taken for both irradiance meter in order to test the performance.

No.	Irradiance (W/m2)		% Error
	Megger Meter	Designed Meter	
1	365	389	0.062
2	385	389	0.01
3	390	389	0.003
4	571	529	0.079
5	596	529	0.127
6	636	599	0.062
7	787	739	0.065
8	897	879	0.02
9	998	949	0.052

Table 3 : System Performance Comparison.

Data from table 3 shows the system performance comparison between Existing Irradiance Meter and Designed Irradiance Meter. From the nine samples taken, the results almost have similarity with very less error which is the highest error is only at 12.7%. The lowest error that almost closed to estimate value is at 0.3%.

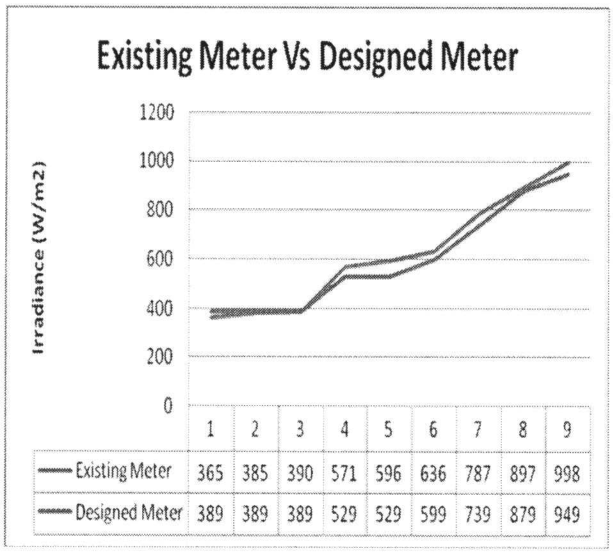

Figure 13 : Existing Irradiance Meter versus Designed Irradiance Meter

Figure 13 illustrate clearly the system performance comparison. From the result obtained, we can see that results of this project have proven that it is able to get results close to the existing irradiance meter with an error below 12%.

Last but not least, a complex and low cost Portable Solar Irradiance Meter has successfully designed as shown in figure 14. Exterior parts have a solar cell and LCD display as to display the solar irradiance.

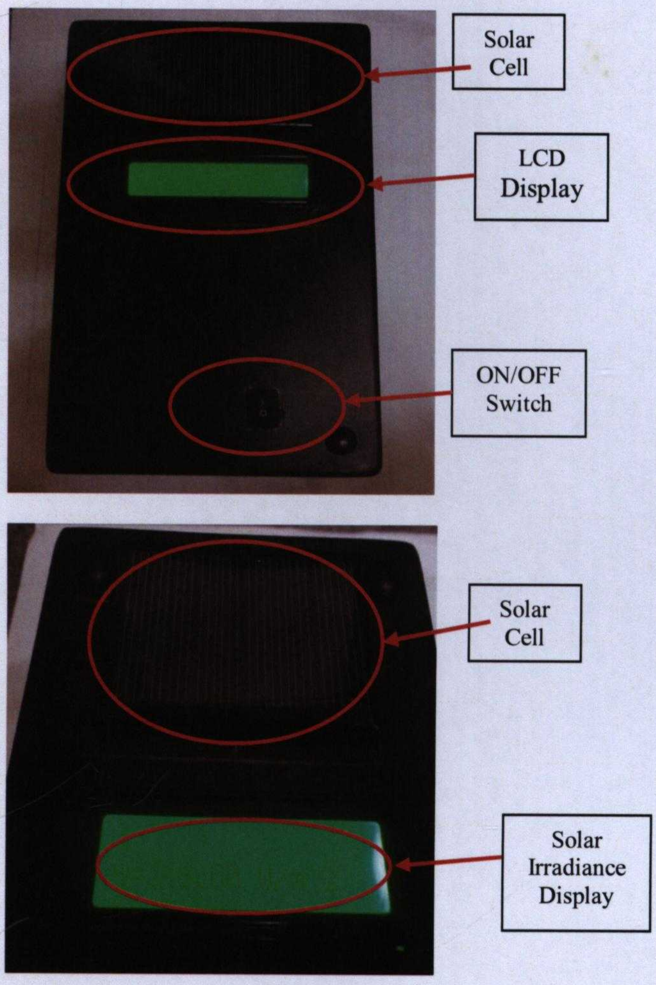

Figure 14 : A Portable Solar Irradiance Meter

V. CONCLUSION

Back to the objectives that have been defined, all the objectives was successfully implemented. Through this project, a portable solar irradiance meter are designed and developed with new controller by using microcontroller PIC16F877A. It is found that the device has come out with data that is reliable and useful. However, there is several weaknesses need to be improved. The major weaknesses that been identified during experiments conducted is the use of PIC16F877A which has a low bit ADC at only 10-bits resolution causing less variation of output. Second, the current sensor(ACS712 x05B) resolution has causing device unable to detect the small current as the resolution of this current sensor is 190mV/A, meaning that for 1mV is equivalent to 5.3 mA whereas the voltage reference(Vref) is 5.0 V and the resolution of 10-bit ADC is 5V/1024 level = 5.0 mV/level = 26.5 mA/level. Therefore, every change in output needs a minimum of 26.5mA.

VI. FUTURE RECOMMENDATIONS

There are a few recommendations for further research in the future to improve the reliability of the device. Firstly, we should change the type of PIC to 12-bits ADC. Therefore, there will be a larger variation in the measurement range and able to close the gap between existing device. Next, improve the circuit that able to amplify the current drawn by solar cell by using a suitable OpAmp (eg LM321) while current sensor able to detect the current.

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