

CHAPTER – I

INTRODUCTION

1.1MOTIVATION

The quality of human life depends to a large degree on the availability of energy. The demand for green renewable sources of energy is growing every year. Presently, the main renewable energy sources are solar, wind, geothermal, biological and hydropower. Conventional fossil energy sources, e.g. petroleum, natural gas and coal, will not be able to meet the growing global energy demand. The need to reduce CO₂ emissions will increase the demand for alternative renewable energy sources. The least expensive alternative energy source is the sun.

The Sun is a primary source of energy for most life forms found on earth.

Photovoltaic (PV) promises clean and reliable source of energy. Most of the currently available solar cells are fabricated from single crystal silicon wafers. Silicon solar cells have high efficiency but their production is very costly and their installation requires very large space.

Despite the significant development over the past decades the high cost of solar cells have remained a limiting factor for the implementation of the solar electricity in a large scale.

These PV cells are now being challenged by the emergence of a third generation of cells, based, for example, on nanocrystalline films, conducting polymers films, and especially dye-sensitized solar cell (DSSC). The DSSC provides a technically and economically credible alternative concept to present PV cells.

DSSCs are currently the most efficient third-generation solar technology available. The fluctuating nature of solar intensity makes it difficult to assess the performance of Solar Cells under direct sunlight. So we need a Standard Solar Simulator along with the measuring module. These modules are very costly and not portable as they are bulky.

1.2 Formulation of problem

DSSCs are claim as a low cost solar cell, but more reduction in cost is necessary to replace conventional energy sources and Si based solar cells.

DSSCs have very low power output as the current and voltage are of very small order. While the voltage ranges in millivolts, the current output is of the order of micro amperes. This necessitates the use of amplifiers.

The conventional ammeters and voltmeters do not provide resolution of that scale. Hence we are forced to find some alternative which can provide us the needed resolution with sufficient accuracy.

For finding out the I-V curve of the DSSC the current and voltage readings for various resistance values have to be obtained. Doing this manually is a hectic as well as inaccurate job. Thus resistances should change automatically and is incorporated by using electronic load.

For obtaining the I-V curve the values of voltage and current for each resistance value have to be multiplexed and then sent to the PC via serial communication using USB port. Also, the PC and DSSC have to be interfaced via microcontroller to obtain various I and V values.

1.3 Objective of Work:

- i. Fabrication of a Dye-Sensitized Solar Cell (DSSC) with TiO_2 nanopowder, ITO/AZO as electrode.
- ii. Interfacing of the DSSC with PC using Arduino Board, to obtain I vs. V plot using MATLAB Software and to find the point of Maximum Power Output.

1.4 Dye-sensitized solar cell (DSSC)

1.4.1 Construction

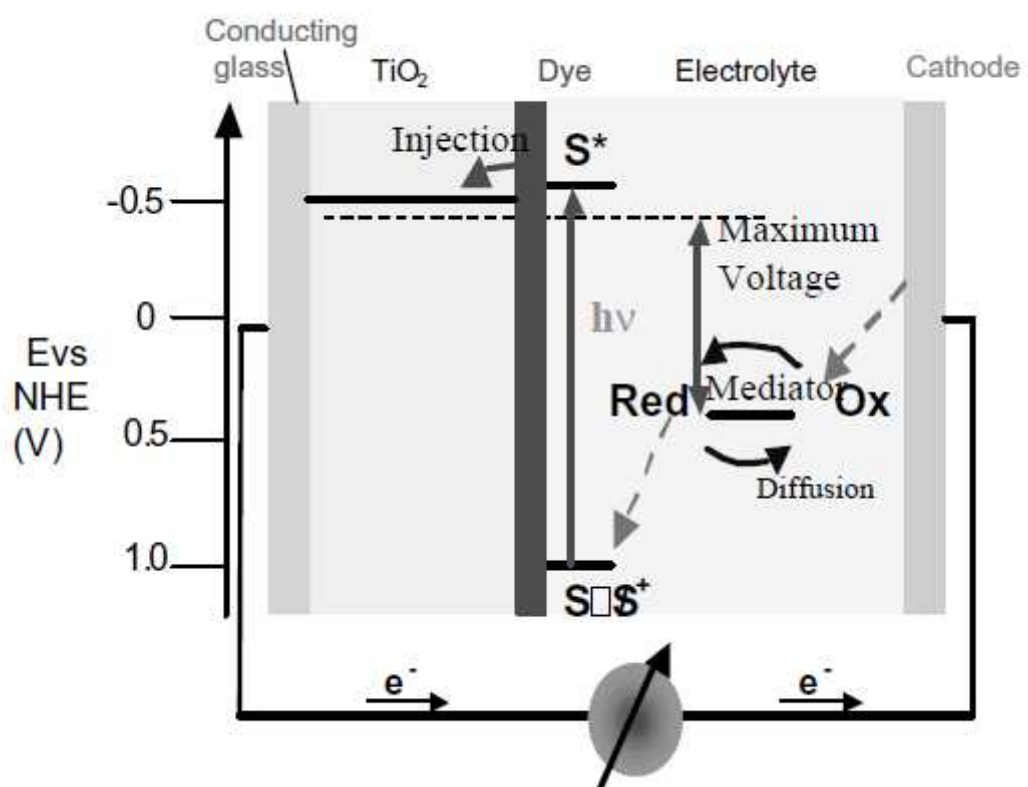


Fig1.1: Construction and Working Principle of DSSC

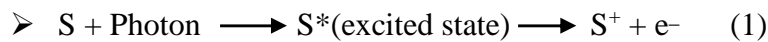
The cell has 3 primary parts.

- On top is a transparent anode made of Indium-doped tin dioxide (ITO) deposited on the back of a (typically glass) plate.
- The plate is then immersed in a mixture of a photosensitive dye and a solvent. After soaking the film in the dye solution, a thin layer of the dye is left covalently bonded to the surface of the TiO₂.
- A separate plate is then made with a thin layer of the iodide electrolyte spread over a conductive sheet. The two plates are then joined and sealed together to prevent the electrolyte from leaking.

1.4.2 Working principle of the dye-sensitized solar cell

Step 1

The absorption of a photon by a dye molecule (S) takes place. After the photon absorption, the dye molecule goes into excited state, S*. Within a very short time, of the order of femtoseconds, the electron is given off to the wide band gap semiconductor. And the excited dye molecule gets oxidized to S⁺.

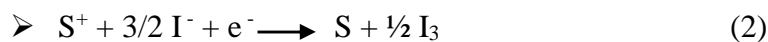


Step 2

The excited electron is given off to the conduction band of semiconductor. A TCO layer is used to collect the electron from the conduction band. The electron then flows through the external load to the counter electrode.

Step 3

The oxidized dye molecules S⁺ is reduced to the original form S by regaining electron from the organic electrolyte solution. The electrolyte solution contains the iodine redox system in which the iodide ions are being oxidized to tri-iodide ions.



1.4.3 Performance of DSSC

Performance of DSSC can be evaluate by calculating following parameters:

- **I_{sc}** : When the cell is short circuited under illumination, the maximum current, the short circuit current (I_{sc}), is generated. Measured in mA.
- **V_{oc}** : Under open circuit conditions no current can flow and the voltage is at its maximum, called the open circuit voltage (V_{oc}). Measured in Volt (V).
- **Fill Factor (FF)**: The fill factor is defined as the ratio of the actual maximum obtainable power to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating the performance of solar cells.

$$FF = \frac{I_m \times V_m}{I_{SC} \times V_{OC}} = \frac{P_m}{I_{SC} \times V_{OC}}$$

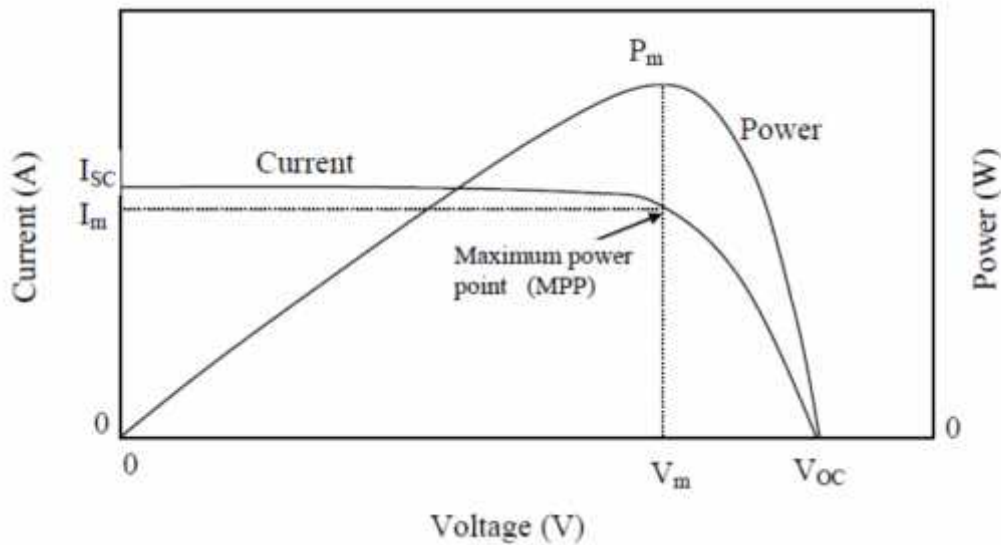


Fig1.2: I-V curve of DSSC

- **Efficiency ()** :

The energy conversion efficiency of the solar cell is defined as the power produced by the cell (P_{MAX}) divided by the power incident on the representative area of the cell (P_{light}):

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100$$

$$= \frac{P_m}{\text{Light intensity}} \times 100$$

$$= \frac{ISC \times VOC \times FF}{\text{Light intensity}} \times 100$$

1.5 Arduino Board

1.5.1 Arduino schematics

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists and anyone interested in creating interactive objects or environments.

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software running on a computer (e.g. Flash, Matlab, Processing, MaxMS).

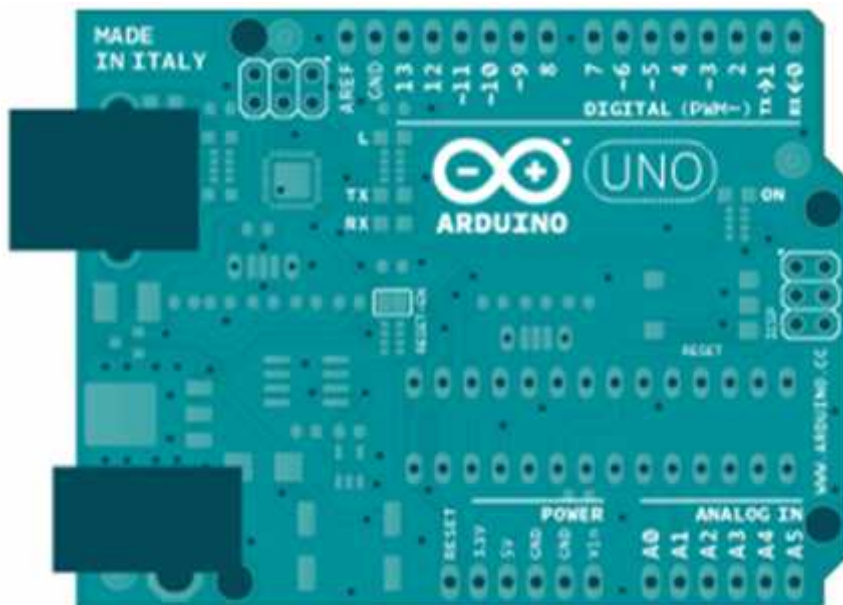


Fig1.3: arduino schematics

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

This board has the following new features:

1> pin out: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible with both the board that uses the AVR, which operates with 5V and with the Arduino Due that operates with 3.3V. The second one is a not connected pin that is reserved for future purposes.

2> Stronger RESET circuit.

3> Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions.

1.5.2 Features

Specifications of Arduino UNO are as follows-

• Microcontroller	ATmega328
• Operating Voltage	5V
• Input Voltage (recommended)	7-12V
• Input Voltage (limits)	6-20V
• Digital I/O Pins	14 (of which 6 provide PWM output)
• Analog Input Pins	6
• DC Current per I/O Pin	40 mA
• DC Current for 3.3V Pin	50 mA
• Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
• SRAM	2 KB (ATmega328)
• EEPROM	1 KB (ATmega328)
• Clock Speed	16 MHz

1.5.3 Applications

- Xoscillo: open-source oscilloscope
- Scientific equipment
- Arduinome: a MIDI controller device that mimics the Monome
- OBDuino: a trip computer that uses the on-board diagnostics interface found in most modern cars
- The Humane Reader and Humane PC from Humane Informatics: low-cost electronic devices with TV-out that can hold a five thousand book library (e.g. offline Wikipedia compilations) on a microSD card
- Ardupilot: drone software / hardware
- ArduinoPhone

1.6 LM324N

This device consists of four independent high-gain frequency-compensated operational amplifiers that are designed specifically to operate from a single supply over a wide range of voltages. Operation from split supplies also is possible if the difference between the two supplies is 3 V to 32 V (3 V to 26 V for the LM2902), and VCC is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, dc amplification blocks, and all the conventional operational-amplifier circuits that now can be more easily implemented in single-supply-voltage systems.

1.6.1 Features

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V
- Low Input Bias Currents: 100 nA Maximum (LM324A)
- Common Mode Range Extends to Negative Supply

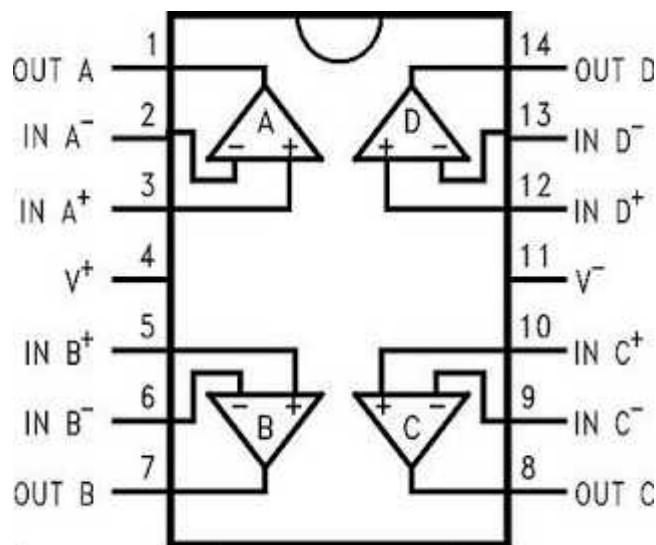


Fig1.4: LM324N pin diagram

1.7 IRFZ20 (MOSFET)

The technology has expanded its product base to serve the low voltage, very low $R_{DS(on)}$ MOSFET transistor requirements. Highly efficient geometry and unique processing have been combined to create the lowest on resistance per device performance. In addition to this feature all have documented reliability and parts per million quality. The transistor also offer all of the well-established advantages of MOSFETs such as voltage control, very fast switching, ease of paralleling, and temperature stability of the electrical parameters. They are well suited for applications such as switching power supplies, motor controls, inverters, choppers, audio amplifiers, high energy pulse circuits, and in systems that are operated from low voltage batteries, such as automotive, portable equipment, etc.



Fig1.5: N-channel MOSFET

1.7.1 Features

- Extremely Low $R_{DS(on)}$
- Compact Plastic Package
- Fast Switching
- Low Drive Current
- Ease of Paralleling

- Excellent Temperature Stability

CHAPTER – II

RESEARCH METHODOLOGY

To improve the efficiency of DSSCs, there are 4 major research areas:

- (i) TiO₂ Photo electrode
- (ii) Dye
- (iii) Electrolyte
- (iv) Counter Electrode

2.1 Experimental Setup for fabrication of DSSC:-

2.1.1 Basic Requirements:-

- ITO/AZO glass plate
- TiO₂ (Powder)
- Dye – Eosin
- Electrolyte- Potassium Iodide (Powder), Iodine (Powder)
- Acetone, Ethanol , Acetonitrile

2.1.2 Tools Required

- Ball milling machine
- Ultra Sonicator
- Hot plate
- Solar Simulator

2.1.3 Sample Preparation:-

2.1.3.1 Preparation of TiO₂ Paste:

- 2g of TiO₂ powder has been taken.

- The sample is then Ball Milled for around 24 hours.
- The ball-milled powder is then suspended in 8ml of ethanol.
- The suspension is then ultrasonicated for 30 minutes.

2.1.3.2 Preparation of Dye Solution:

- 20mL of 1 mm eosinY is properly dissolved in ethanol and then ultrasonicated for 30 minutes.

2.1.3.3 Preparation of Electrolyte Solution:

- 0.5M of Potassium Iodide is suspended in Acetonitrile.
- Further addition of 0.05M Iodine is being done in the obtained solution and ultrasonicated again for 60 minutes.

2.1.4 Procedure for fabrication of DSSC:-

2.1.4.1 Step 1: preparation TiO₂ Photo Electrode:

- Conductive side of ITO glass is ascertained with the help of multimeter.
- A mask of 2x2 cm is prepared with the help of scotch tape over the conducting side.



Fig2.1: masking of ITO Glass

- The paste of TiO₂ is then evenly spread with the help of glass rod.

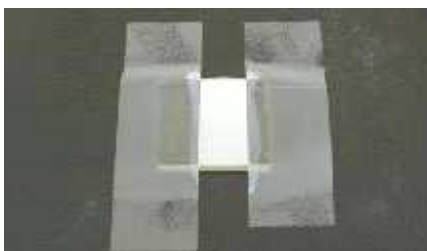


Fig2.2: TiO₂ spreaded

- After the removal of Scotch Tape Mask, the sample is then annealed over the hot plate for nearly 10 minutes at 100 °C.



Fig2.3: annealing process



Fig2.4: Hot Plate and Dye

2.1.4.2 Step 2 Dye absorption:

- The TiO₂ spread ITO glass is then dipped into the dye solution and soaked for 10 minutes.
- The sample is also being put for mild heating for faster absorption and coloration.
- The sample is then washed with De-Ionized water & Ethanol to remove extra dyes from the ITO surface.



Fig2.5: ITO dipped in dye solution

2.1.4.3 Step 3 Preparation of counter electrode:

- The graphite layer is spread over counter electrode for the purpose of catalysis.



Fig2.6: Counter electrode

2.1.4.4 Step 4 Final assembly:

- Both the electrodes are sandwiched together with the help of binder clips with conducting side facing each other.



Fig2.7: prepared DSSC

- It is also ensured that the sides are in little offset condition so that terminals can be realized for the connection with multimeter.
- Electrolyte Solution is then added from either side and allowed to spread over the sandwiched junction.



Fig2.8: ultra sonicator for mixing of solutions



Fig2.9: the Solar Simulator

2.2 Construction of Module

2.2.1 Signal Conditioning (Initial approach)

2.2.1.1 Current Measurement:-

This is required for amplifying the values of current and voltage so that they can be measured by the analog pin of the microcontroller. Since it is not possible to measure the current directly using the analog pin, so we convert it into voltage using a current to voltage converter and measure the current indirectly using the resistance value.

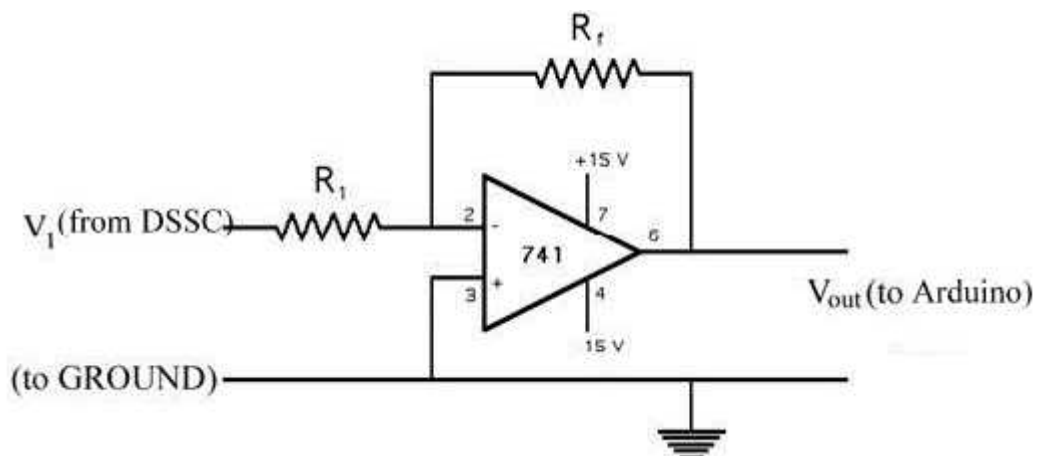


Fig2.10: the Current to Voltage Converter for measuring the current

2.2.1.2 Voltage Measurement:-

Since the voltage can be measured directly using the analog pin of microcontroller, so the negative terminal of DSSC is grounded while the positive terminal is inserted into the analog pin A0 of Arduino Board.

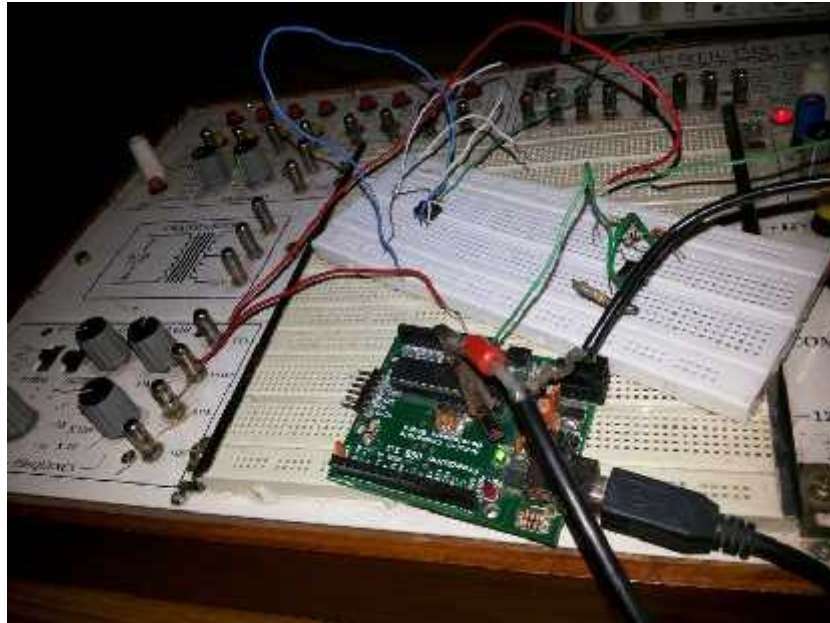


Fig2.11: The circuit connection to the Arduino board for obtaining the waveforms

2.2.2 Signal Conditioning (Final approach)

2.2.2.1 Voltage Measurement:-

Since for getting the plot of voltage and current we require various values of voltages. Thus, this circuit fulfils our need by changing the drain resistance of the MOSFET. U1B of LM324N is used for voltage measurement and the circuit provides a gain of 6.6 so as voltage can be read efficiently and effectively.

2.2.2.2 Current Measurement:-

Change in gate voltage of MOSFET leads to the change in current which passes through the circuit. The concept of initial signal conditioning is used here and current is converted to voltage which is then suitably amplified. U1A of LM324N is used for measuring the converted voltage and provides a gain of 33.

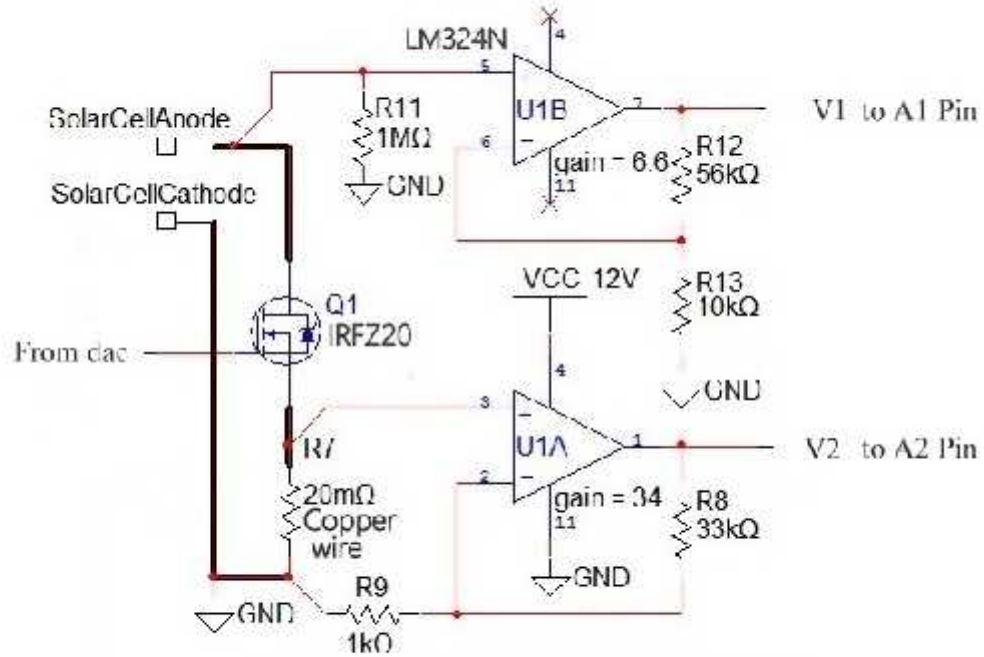


Fig2.12: circuit for voltage and current signal conditioning

2.2.2 Analog to Digital Conversion

The `analogRead()` command converts the input voltage range, 0 to 5 volts, to a digital value between 0 and 1023. This is done by a circuit inside the Arduino called an **analog-to-digital converter** or **ADC**. In particular Arduino divides the range of 0 to 5 volts into 1024 different voltage levels or intervals. 0 volts is in the interval 0, and 5 volts in the interval 1023. In this way, 2.5 volts would be in the interval 511 as well as 2.52 volts or 2.5103. The formula used in this analog to digital conversion is given as:

$$\frac{1023}{5} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}}$$

Where, ADC Reading is the digital value used and Analog voltage measured is the voltage reading from the DSSC or the signal conditioner. The ADC has a 10 bit

resolution thus the number of intervals which can be used is given as $2^n - 1$ where n = number of signalling levels. The Arduino Board has a upper range of 5V so the maximum analog value=5.

2.3 COMPILER USED

The compiler used for uploading the codes to the Arduino board is Arduino 1.0. Codes to be fed for the microcontroller to perform the desired functionality is burnt on to the memory of Arduino with the help of this compiler.

2.5 Complete Circuit and its working

Circuit implemented on U1C of LM324N is used for digital to analog conversion. The DAC thus implemented is of 10 bit resolution with accuracy of 0.1% and outputs voltage in the range of 0-10V. Output of the DAC is fed to the gate of the MOSFET for driving the drain resistance (R_d). Drain of the MOSFET is connected to the voltage output from solar cell while the source is grounded via a 20mohm resistance (preferably copper wire of known resistivity length and cross section area). U1B and U1A are used for voltage and current sampling respectively. This circuit operates on an input voltage of max of 0.75mV from the solar cell. As the voltage of the DSSC is in range of mV while current is generally in the range of μA so a higher gain is required in the current to voltage convertor circuit.



Fig2.14: Implemented circuit

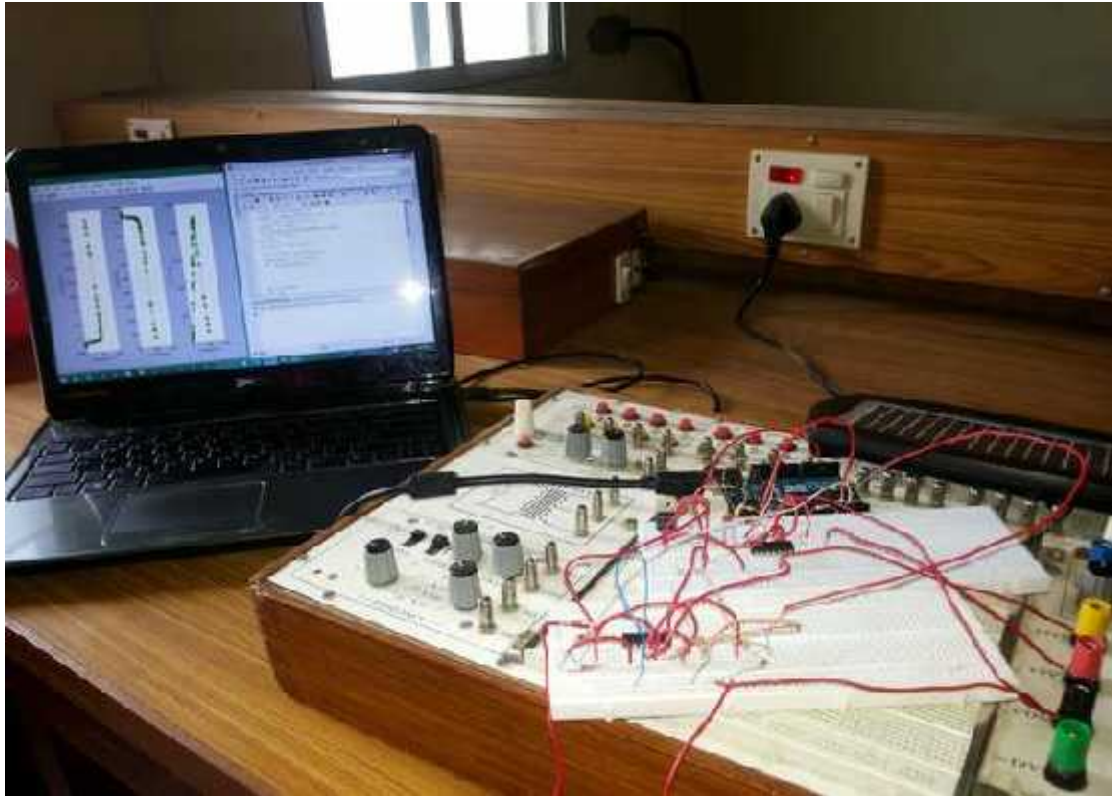


Fig2.15: Implemented circuit with Arduino interfaced to PC

CHAPTER – III

RESULTS AND DISCUSSION

3.1 Initial results and comparisons

Initially in this project short circuit voltage and a value of current flowing through any known resistance was calculated and plotted. These observations were compared with the value obtained from manual calculation and was found in good agreement. Multiplexing data for current and voltage was the further process which was based on the operations of this initial basic circuit structures used. The left graph of each figure shows the digital data received from the serial port in the range 0-1023 while right graph shows the corresponding analog representation.

3.1.1 Current vs No of samples for a Conventional Solar Cell

The value of current for a Conventional Solar Cell was measured under cloudy weather conditions and was found to be 1uA. We are using 1Mohms resistance to obtain the current reading. Current has been plotted on Y axis against no of samples taken on X axis.

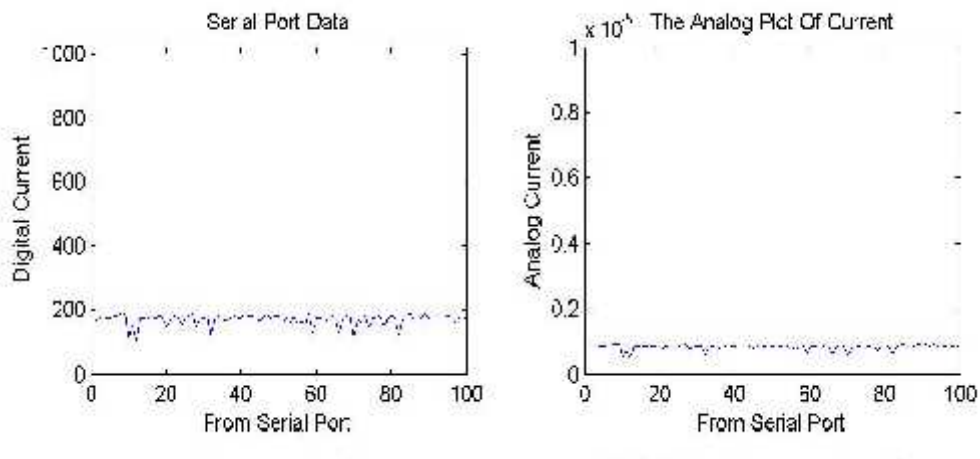


Fig3.1: Current for a conventional Solar Panel

3.1.2 Voltage vs No of samples for a Conventional Solar Cell

The value of open circuit voltage for a Conventional Solar Cell was measured under cloudy weather conditions and was found to be 4 V. Under standard conditions the voltage rating of the cell is 7.5 V. The Voltage has been plotted on Y axis against no of samples taken on X axis.

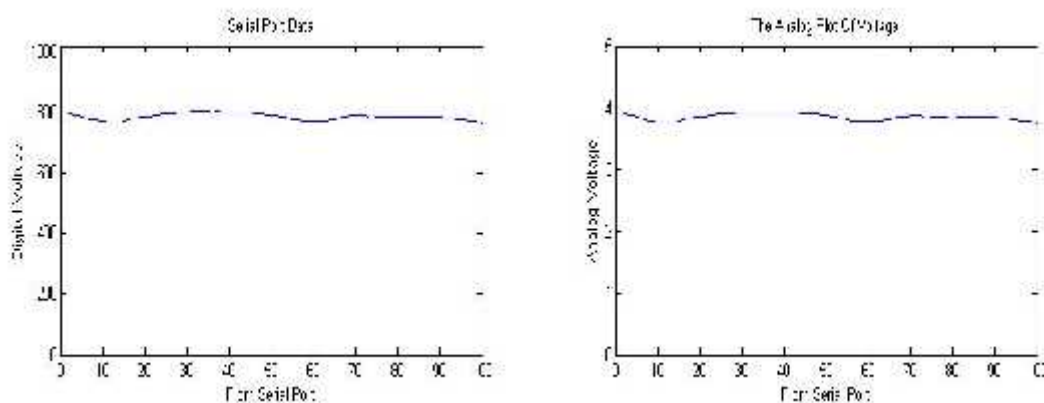


Fig3.2: Open circuit Voltage for a conventional Solar Panel

3.1.3 Voltage vs No of samples for a Dye-Sensitized Solar Cell

The value of open circuit voltage for a DSSC Cell was measured under clear weather conditions and was found to be 38mV. Voltage has been plotted on Y axis against no of samples taken on X axis. Under standard conditions the voltage rating of the cell is 70mV.

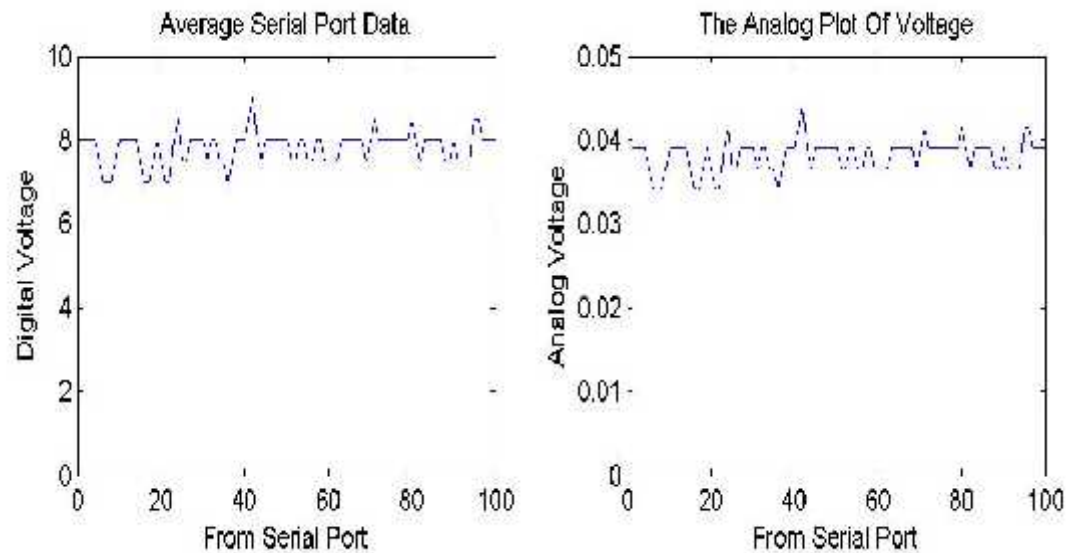


Fig3.3: The open circuit voltage of our fabricated DSSC

3.1.4 Current vs No of samples for a Dye-Sensitized Solar Cell

The value of current for a DSSC was measured under clear weather conditions and was found to be 2 μ A. We are using 1Mohms resistance to obtain the current reading. Current has been plotted on Y axis against no of samples taken on X axis.

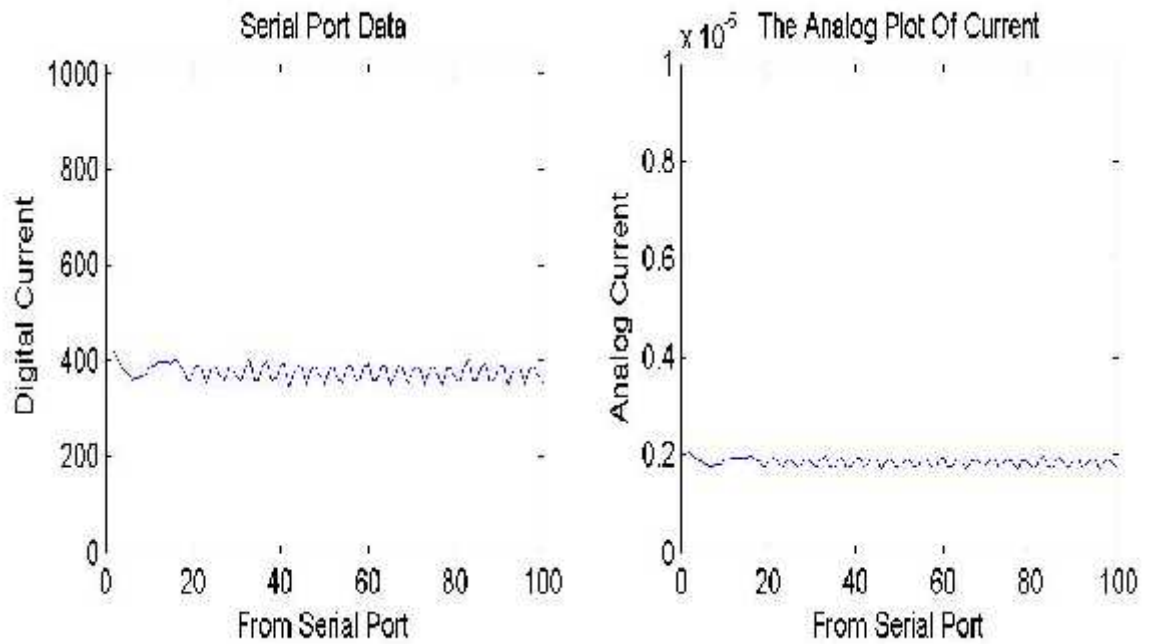


Fig3.4: The value of current of our fabricated DSSC

3.2 Efficiency enhancement

We fabricated DSSCs with different combination of electrolyte and Dye. Two different glasses were used ITO and AZO.

(All measurements were taken under AM 1.5, 1000 W/m², from Keithley solar simulator, semiconductor material used- TiO₂)

- ITO coated glass, Electrolyte used- KI, cell area – (2.5*2.5) cm², active area- (2*1.5) cm²,
 - V_{OC} with Eosin Y Dye - 30mV
 - V_{OC} with Ru Dye - 112 mV
- ITO coated glass, Electrolyte used- LI, cell area – (6*3.5) and (3.5*1.5) cm², active area- (2*1.5) cm²,
 - V_{OC} with Eosin Y Dye - 99mV
 - V_{OC} with Ru Dye - 657 mV
- AZO coated glass, Electrolyte used- LiI, cell area – (2.5*3.5) active area- and (1*1.5) cm²,

- V_{OC} with Eosin Y Dye - 152mV
- V_{OC} with Ru Dye - 307mV

Above results shows that LiI is better electrolyte compare to KI. The addition of LiI into liquid electrolyte can enhance the performance of DSSCs. The reason is that the small-radius Li^+ can deeply penetrate into the mesoporous dye-coated nanocrystalline TiO_2 film and form an ambi-polar Li^+-e^- with the electrons in the conduction band of TiO_2 , which increases the transport speed of electrons in nanocrystalline TiO_2 network and enhances the performance DSSCs. Also KI is not properly solvable in liquid electrolyte.

From DSSCs performance measurements we can conclude that Ru Dye gives better performance compare to Eosin Y Dye. Ru Dye sensitized electrode has larger electron life time values compared with those for the Eosin-Y sensitized electrode.

We fabricated DSSCs with ITO and AZO electrodes. DSSC fabricated with ITO electrode gives better performance compare to AZO electrode. But as we know there is limited availability of the element indium on earth, and both Zinc and Aluminium are inexpensive and abundant material. This gives AZO an advantage when comparing with ITO as it is relatively cheap.

3.3 Final results

These data are obtained from the solar panel which was partially covered by black paper and a cross section of $1 \times 1 \text{ cm}^2$. This was done in order to decrease the voltage output of the panel as this circuit works properly only for voltages below 0.75V. Current and voltage data were multiplexed and the data were kept in a text file which was then read by MATLAB to obtain the plots. These plots consists of three subplots the leftmost is the I-V curve in 4th quadrant the middle plot is the I-V curve in 1st quadrant and the rightmost plot is the P-V plot.

3.3.1 Plot obtained at a solar cell input of 560mV

This circuit operates best at the higher values of its range with optimum performance at near 0.75V thus at this value the plot obtained for current and voltage is very close to the theoretical plot with very less variations or error.

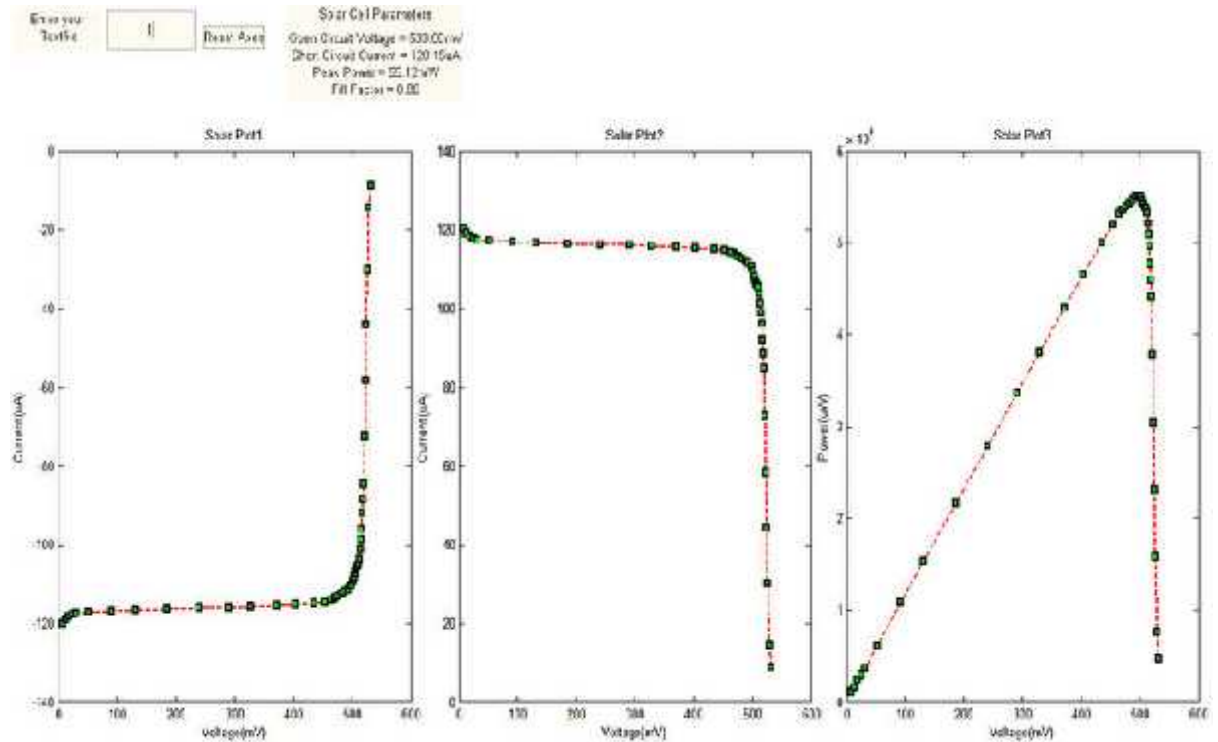


Fig3.5: I-V and P-V plot at 560mV input

3.3.2 Plot obtained at a solar cell input of 157mV

Near the minimum of the operating range the output plot is prone to more DAC errors. Thus in one DAC cycle less data is acquired which results in some error that corrupted in the results.

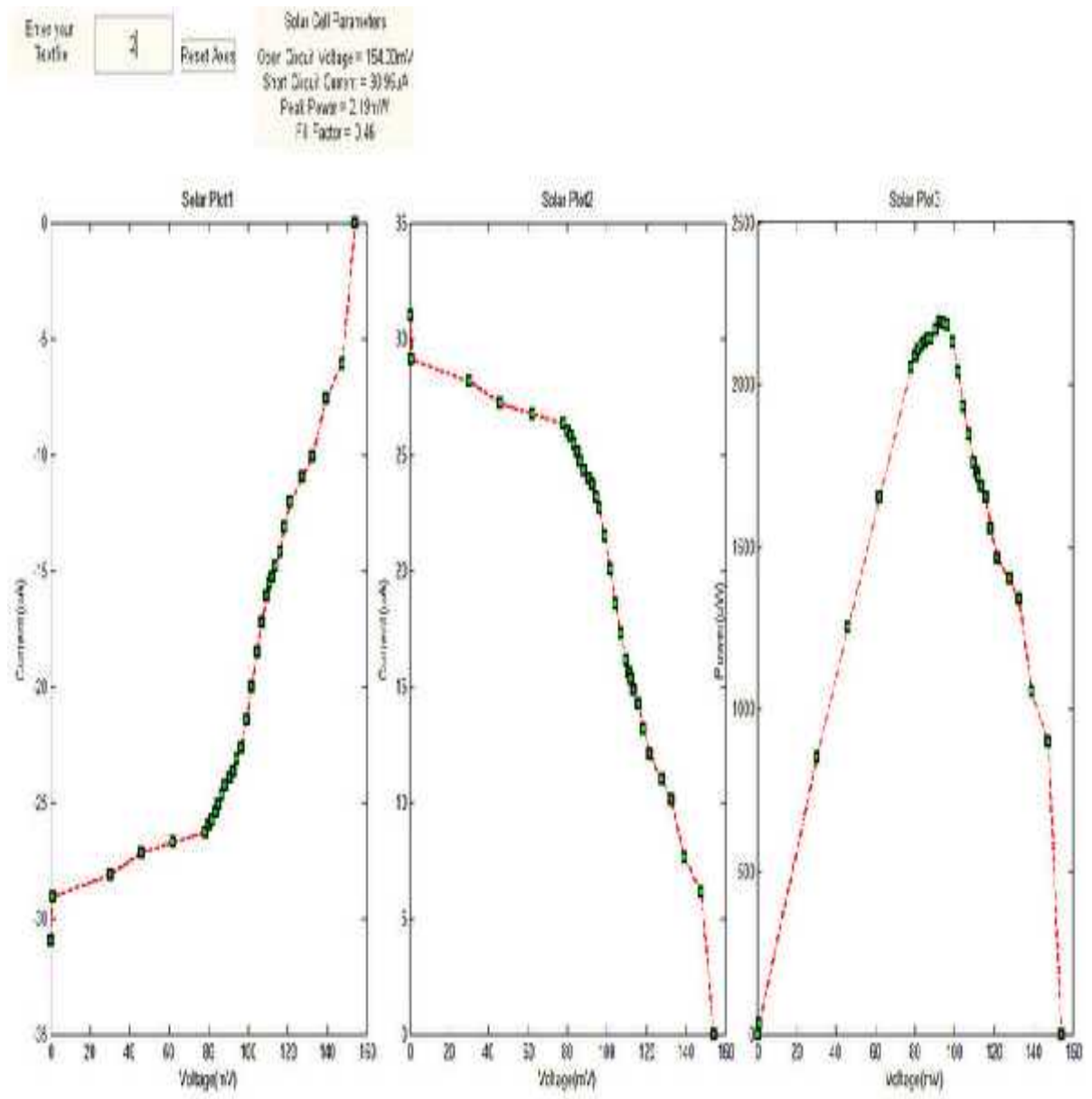


Fig3.6: I-V and P-V plot at 157mV input

3.3.3 Plot obtained at a solar cell input of 200mV

Plots of the data obtained in the middle range are less prone to errors than those at the minimum side of range and are more prone to error than those at the maximum side of the range.

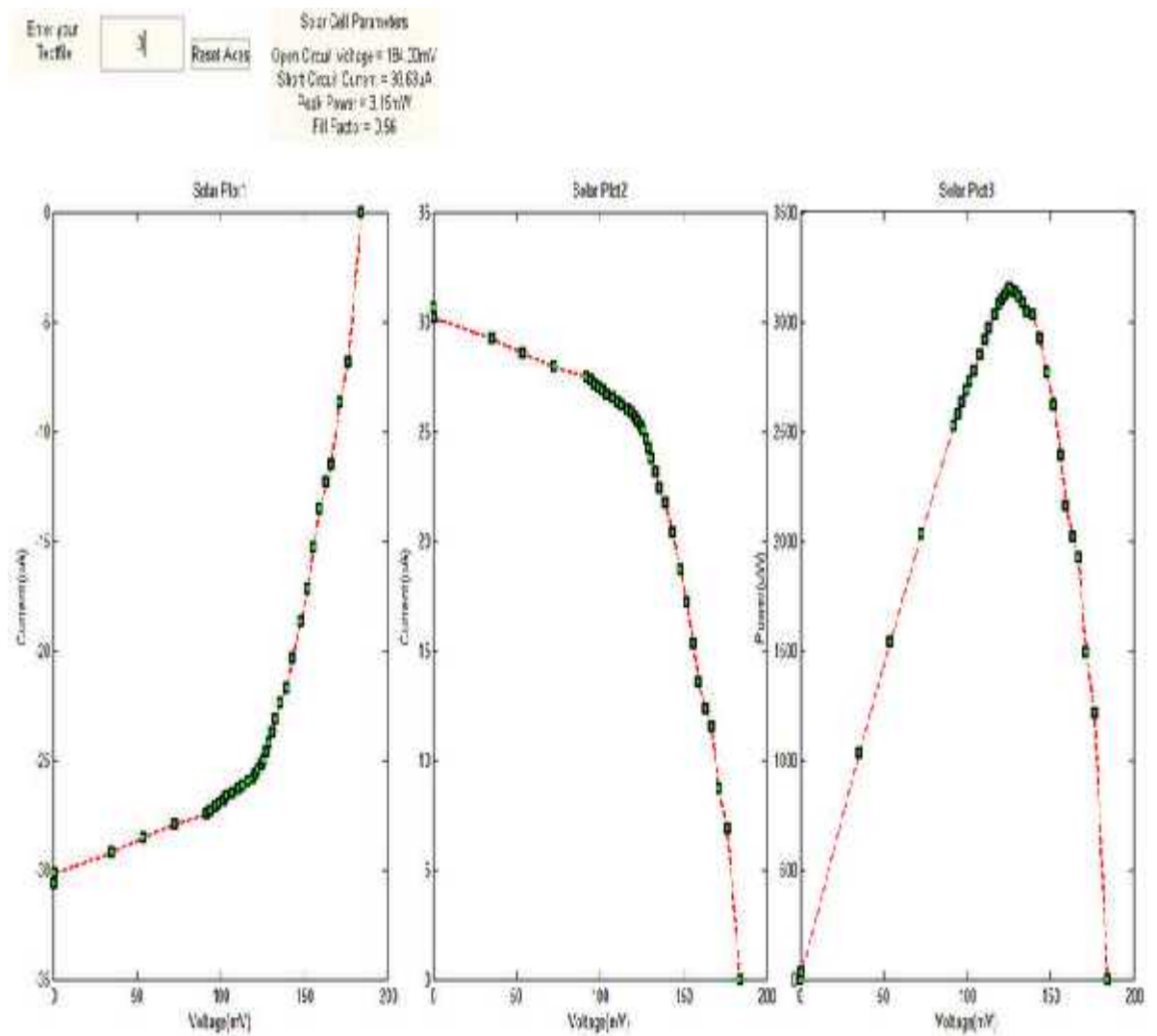


Fig3.7: I-V and P-V plot at 200mV input

3.4 Reproducibility of results

This circuit was checked for its reproducibility whether or not it gives a constant plot even after days of its implementation. The results obtained were quite good as even after 5 days the I-V plot obtained was quite same

as that obtained on the 1st day of analysis. The conditions were kept almost similar so as to check for it's reproducibility.

3.4.1 Day 1 of analysis

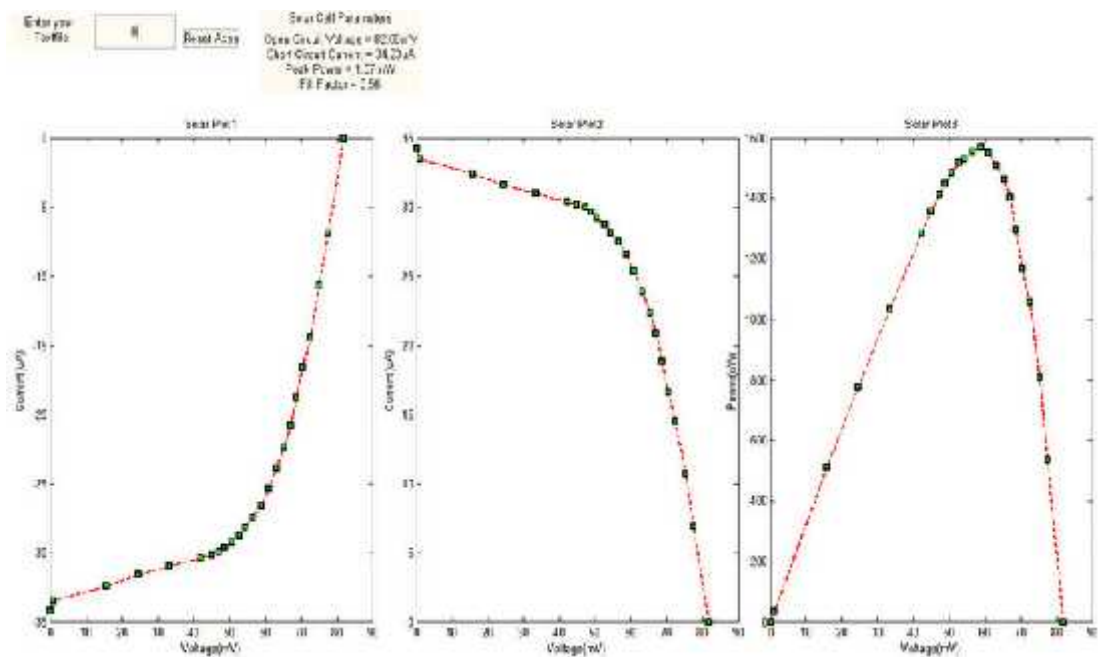


Fig3.8: V_{oc} =82mV and I_{sc} =34.23 μ A

3.4.1 Day 2 of analysis

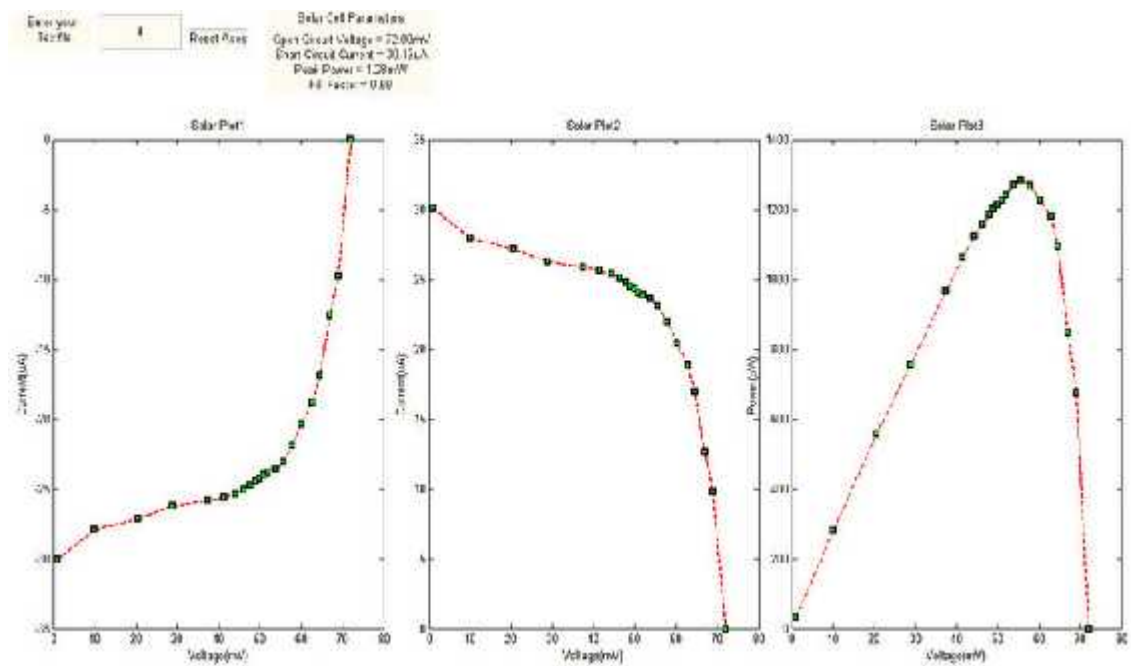


Fig3.9: $V_{oc}=72\text{mV}$ and $I_{sc}=34.23\mu\text{A}$

3.4.1 Day 3 of analysis

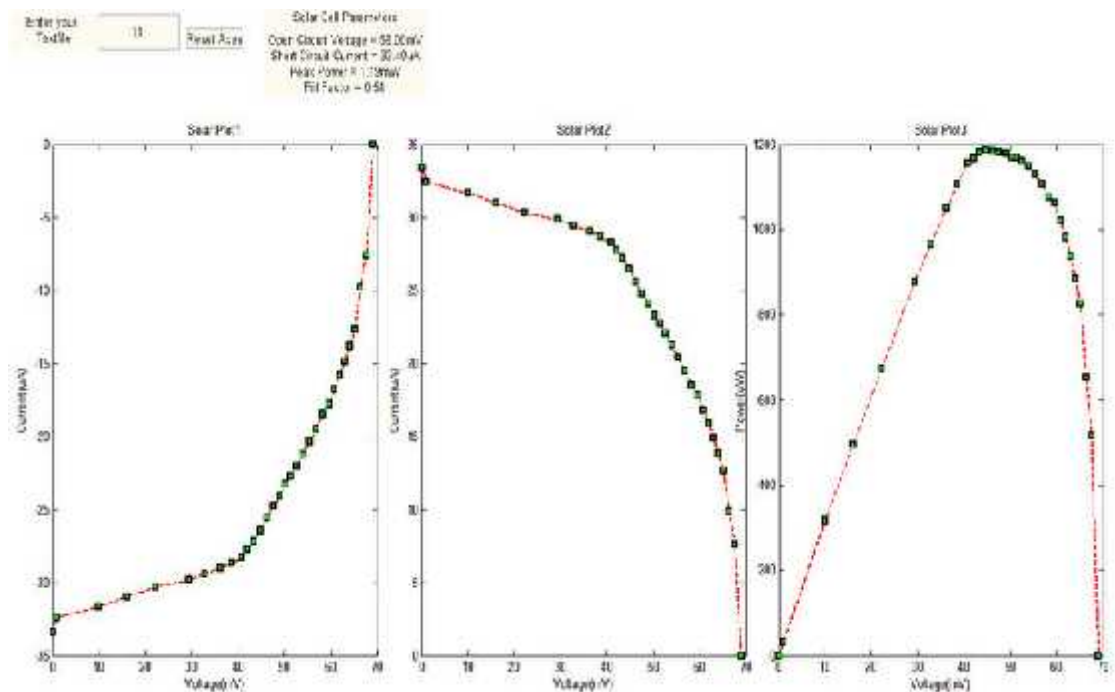


Fig3.10: $V_{oc}=69\text{mV}$ and $I_{sc}=33.4\mu\text{A}$

3.4.4 Day 4 of analysis

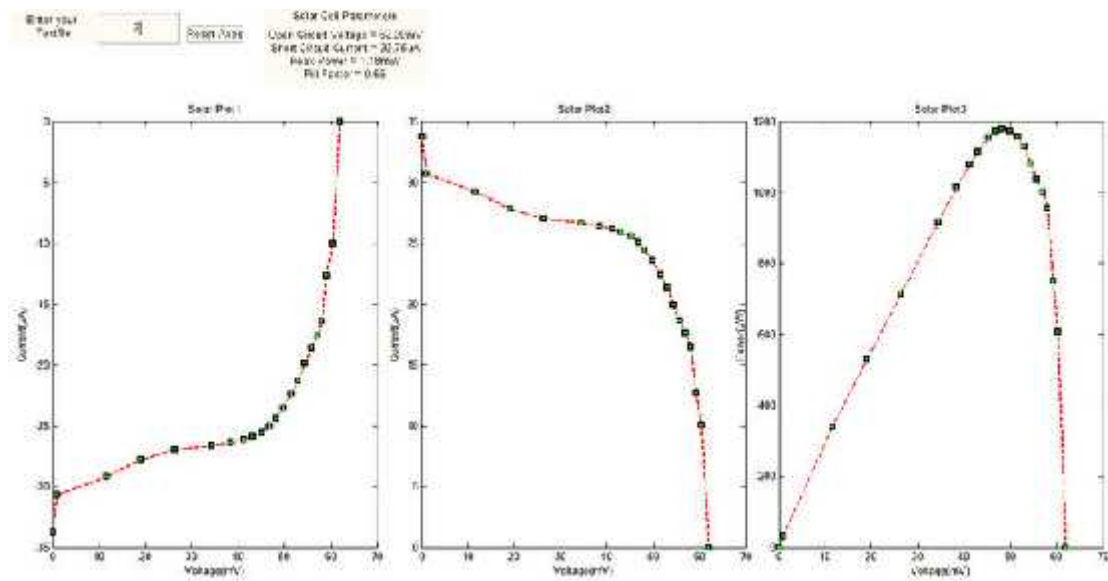


Fig3.9: $V_{oc}=62\text{mV}$ and $I_{sc}=33.75\mu\text{A}$

3.4.5 Day 5 of analysis

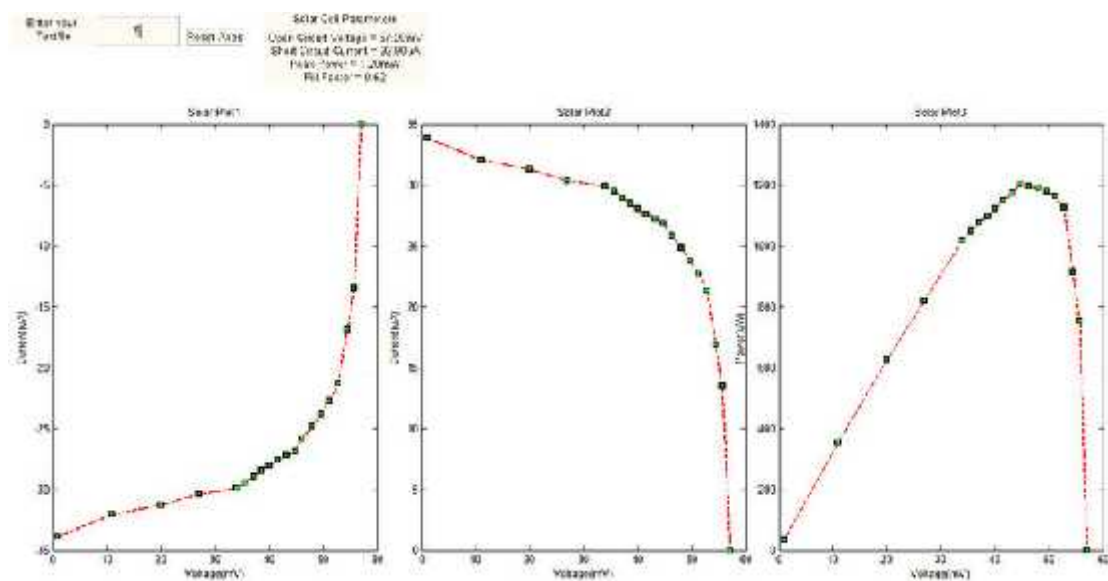


Fig3.9: $V_{oc}=57\text{mV}$ and $I_{sc}=33.90\mu\text{A}$

CHAPTER - IV

CONCLUSION

In this project we successfully fabricated the dye sensitized solar cell. To assess its performance we measured its voltage and current values for a fixed resistance. We further plan to plot the I-V curve by taking more values of current and voltage by varying load resistance manually as well as electronically. This I-V curve can be used to find the point of maximum power.

The estimated cost of the module which we are trying to design is about 5,000 INR which is about 1% of the cost of commercially available modules.

Above results shows that LiI is better electrolyte compare to KI whereas Ru Dye gives better performance compare to Eosin Y Dye while DSSC fabricated with ITO electrode gives better performance compare to AZO electrode.

This circuit performs for a maximum range of 750mV and this is suitable for plotting of I-V characteristics of DSSC and also for Si based Solar Cells whose output voltage lies in this range.

This circuit gives near to theoretical results when the input voltage from the Solar Cell is near the maximum input voltage value and this error increases as one moves towards the minimum range. This is due to the reason that towards the minimum range DAC is not able to take samples that is there is less DAC write which occurs and thus values are not obtained throughout the range of DAC.

The reproducibility of implemented circuit was found by taking readings of the Solar Cell for 5 consecutive days and the plots obtained were in good agreement with each other. Thus, this circuit provides reproducible results even after passage of time.

CHAPTER V

FUTURE SCOPE

DSSCs though are cost effective but have a very limited lifetime of 4 -5 days because of the liquid electrolyte. Also the electrolyte being in liquid state makes it difficult to carry or store for a long time. The power rating of these cells is quite low and need a comprehensive research. These fields provide a lot of scope for research and improvement so that these cells can be extensively used.

The I-V characteristics of the DSSCs show a dependence on temperature. We plan to use sensors to measure the temperature at the time of measurement so that fluctuations in the I-V curve can be avoided.

The reproducibility of the circuit is good but needs further improvements so that the temperature dependence of resistances used can also be included in the circuit implementation.

This circuit is designed for a maximum of 750mV which is not enough for silicon panels with higher readings. This circuit thus can be modified to obtain I-V plots even for larger value of voltages.

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