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Dynamic Glass Project

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Abstract

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More power from the sun hits the Earth in a single hour than humanity uses in an entire year. However, despite this abundant, reliable and pollution free source, constraints such as cost, inconsistency, aesthetics and space prevent widespread utilization.

To solve the world's growing need for clean power, development is required of new solar technologies which are efficient, stable, sustainable and seamlessly incorporated into modern living.

This bachelor's thesis has been made in partnership with Peafowl Solar Cell during the spring 2020, with the aim to develop a model with focus on smart shading regulated and thereby be able to better predict future energy.

The results show that it is possible to use small electronic components can be used to control larger model of dynamic glass. The purpose of having the external and internal sensor in this model is to be able to compare between indoor and outdoor temperature and light values which in turn can be sent to the microprocessor and after that it is decided how much shading should be given by glass.

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Smart shading regulated by the time at specific voltage

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School of Electrical Engineering and
Host company: Peafowl solar power
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Sammanfattning

Mer kraft från solen träffar jorden på en enda timme än mänskligheten använder under ett helt år. Trots denna rikliga, pålitliga och föroreningsfria källa förhindrar emellertid begränsningar som kostnad, inkonsekvens, estetik och rymd ett utbrett utnyttjande.

För att lösa världens växande behov av ren kraft krävs utveckling av nya soltekniker som är effektiva, stabila, hållbara och sömlöst integrerade i modernt liv.

Denna kandidatuppsats har gjorts i samarbete med Peafowl Solar Cell under våren 2020, i syfte att utveckla en modell med fokus på smart skuggning reglerad och därmed kunna förutsäga framtida energi bättre.

Resultaten visar att det är möjligt att använda små elektroniska komponenter för att styra en stor modell av dynamiskt glas. Syftet med att ha den externa och interna sensorn i denna modell är att kunna jämföra mellan inomhus-utomhustemperatur och ljusvärden som i sin tur kan skickas till mikroprocessorn och efter det beslutas hur mycket skuggning som ska ges av glas

Acknowledgements

First of all, I would like to thank Peafowl solar power for giving me the opportunity to do this project as my bachelor's thesis.

I would like to express my sincere gratitude to my supervisor Jacinto Sá at Peafowl solar power for his invaluable guidance, comments and suggestions throughout the project. I cannot thank you enough for your time.

I am also very thankful to my supervisor Mats Ekberg at Uppsala University and my examiner, for their valuable feedback and ideas to improve my work.

Abbreviations

- **IoT** - Internet of things
- **PSP** - Peafowl solar power
- **DSC** - Dye Sensitized Solar cell
- **ISC** - Short circuit current
- **EOC** - Open circuit potential
- **FF** - Fill factor
- **MPP** - Maximum Power Point
- **Li-on** - Lithium-ion batteries
- **DC** - Direct current
- **SPI** - Serial Peripheral Interface
- **HVOUT** – Hight Voltage Output
- **DPSC** – Direct Plasmonic Solar Cell
- **EV**- Electric vehicle
- **RF433 MHz** - Transmitter/Receiver Module
- **LDO** - Low-dropout regulator

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Introduction

1.1 Background

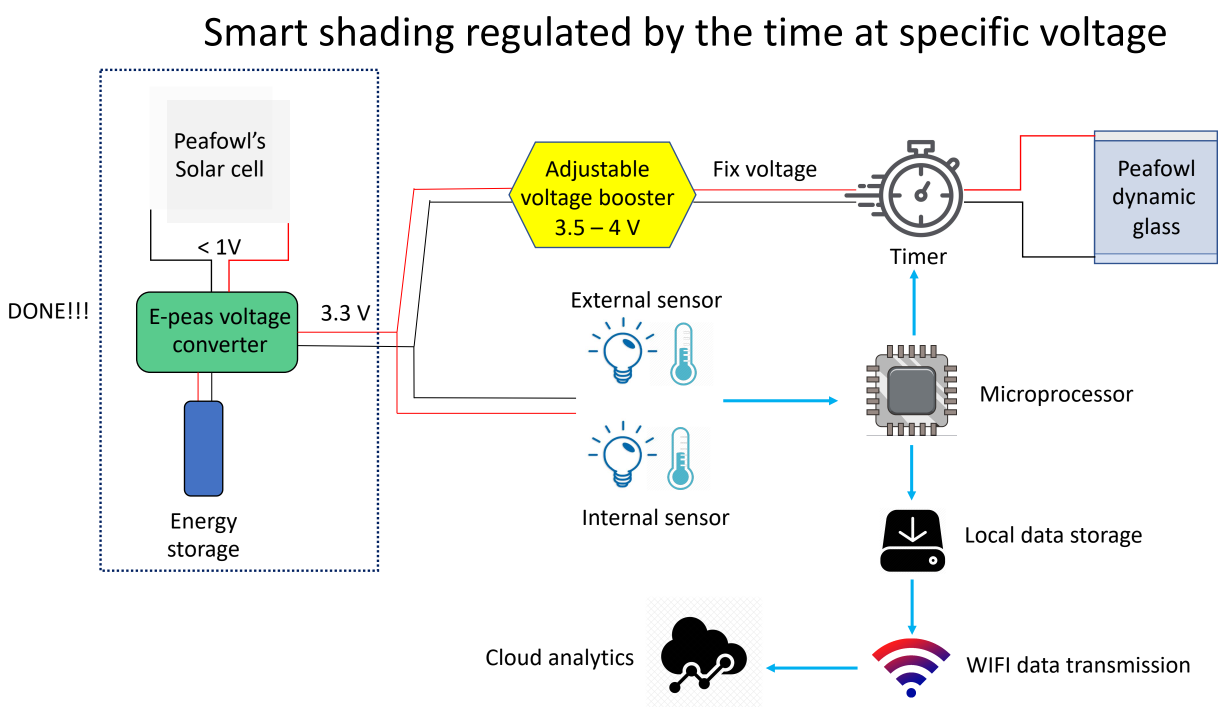
A DPSC converts light into electricity using plasmonic nanoparticles as the active, photovoltaic material. Plasmonic nanoparticles can absorb up to ten times as much light as other known materials. Because the PSC is so efficient at converting the light it intercepts into electricity, it can produce electricity even when very little light is intercepted. This is the key to the ultra-high transparency of the cell [1].

Direct plasmonic solar cells should not be confused with plasmonic-enhanced solar cells that use plasmons to boost performance of other technologies, where the photovoltaic effect occurs in another material.

The Peafowl Solar Cell is similar in structure to conventional organic solar cells and can therefore be inexpensively manufactured through a printing process in room temperature.

1.2 Purpose

Power from the sun can be used in different ways. This bachelor's thesis is part of a greater work whose purpose is to make world's first direct plasmonic solar cell, with applications in self-powered dynamic windows and integrated power supply for smart sensors and devices for the IoT. This project has made together with Peafowl solar power to solve the world's growing need for clean power for which development is required of new solar technologies which are efficient, stable, sustainable and seamlessly incorporated into modern living.



FET 1.1: Project overview shows all steps of the system. [Peafowl solar power]

1.3 Objectives

This project intends to focus on developing a method for PSP innovative technology that can generate power from transparent surfaces, such as windows and displays, and converts both indoor and outdoor light into electricity. The aim of making these technologies is to make it possible to forecast that solar cell supply the clean power in future for the world, rather than forecasting the correct amount of consumed volumes at a certain hour. The objectives of this bachelor's thesis are thus to:

- Create a model for control of dynamic glass based on sensor data, by comparing the signal between the external sensor and the internal sensor.
- Apply the created model to simulation the data from the smart sensor by microprocessor in order to transmit data by RF433 MHz module to create future consumption imbalance data, mainly by finding parameters that affect the behaviour of electricity consumption.

1.4 Limitations

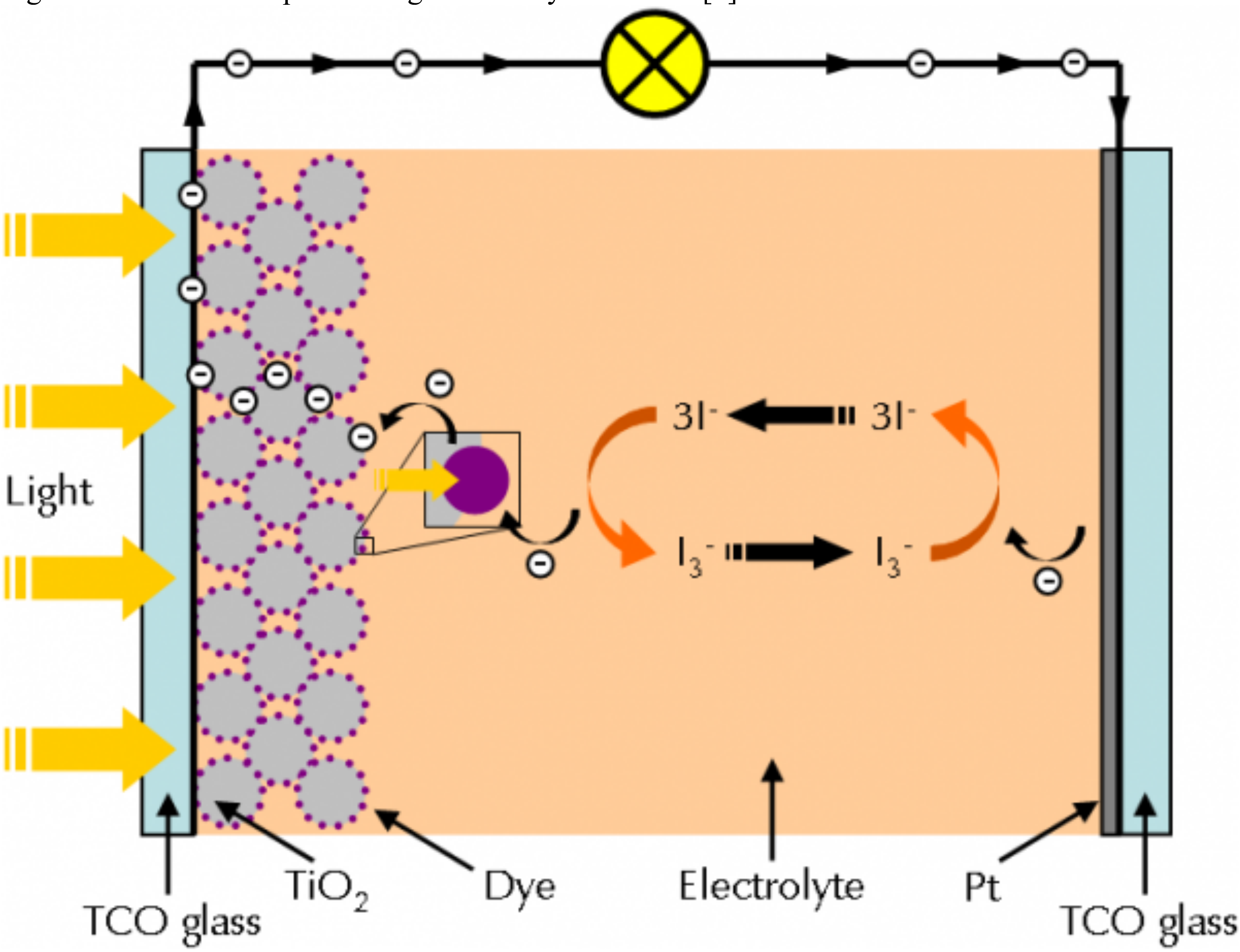
The project is extensive and is expected to require more than 10 weeks on PSP. Therefore, a complete system will not be presented. However, some parts of one of the solution proposals can be verified practically by a test circuit board which can be used for measurement.

Theory

2.1 Dye Sensitized Solar Cells

2.1.1 Setup of a Dye Solar Cell

Figure 2.1 shows a simplified diagram of a dye solar cell [2].



FET 2.1: Simplified setup of a dye solar cell. [2]

The anode of a DSC consists of a glass plate which is coated with a transparent conductive oxide (TCO) film. Indium tin oxide (ITO) or fluorine doped tin oxide are most widely used. A thin layer of titanium dioxide (TiO2) is applied on the film. This semiconductor exhibits a high surface area because of its high porosity.

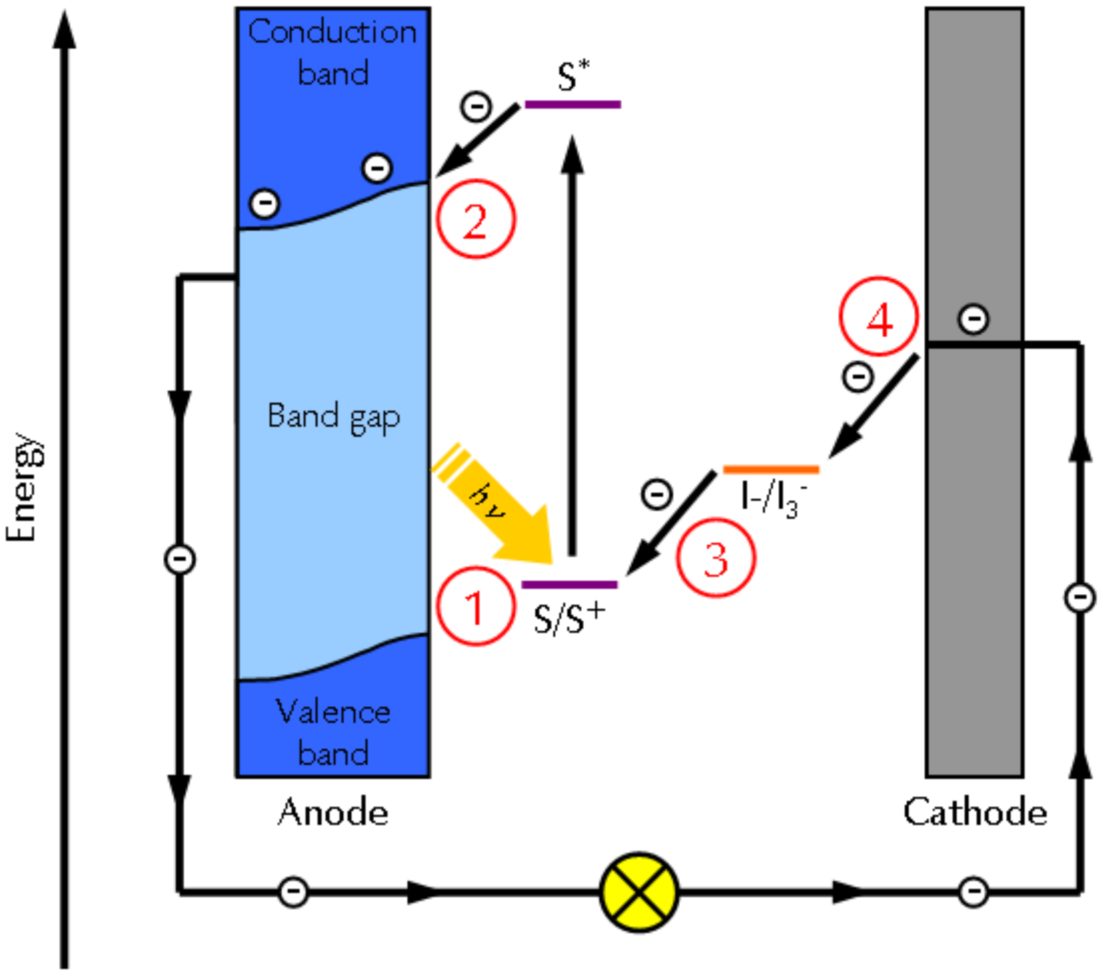
The anode is soaked with a dye solution which bonds to the TiO2. The dye – also called photosensitizers – is mostly a ruthenium complex or various organic metal free compounds. For demonstration purposes, also plain fruit juice (such as from blackberries or pomegranates) can be used. They contain pigments which are also able to convert light energy into electrical energy.

The cathode of a DSC is a glass plate with a thin Pt film which serves as a catalyst. An iodine/triiodine solution is used as the electrolyte.

Both electrodes are pressed together and sealed so that the cell does not leak. An external load can be powered when light shines on the anode of the dye solar cell.

2.1.2 Principle of a Dye Solar Cell

As the name implies, the mechanism of dye solar cells is based on the photo electrochemical processes. Figure 2.2 depicts an energy diagram of a dye solar cell. The following section describes all relevant electrochemical processes.



FET 2.2: Energy diagram of a dye solar cell. [2]

STEP 1: The dye molecule is initially in its ground state (S). The semiconductor material of the anode is at this energy level (near the valence band) non-conductive.

When light shines on the cell, dye molecules get excited from their ground state to a higher energy state (S*), see equation 1.

$$S \xrightarrow{h\nu} S^*$$

(Eq.1)

The excited dye molecule has now a higher energy content and overcomes the band gap of the semiconductor.

STEP 2: The excited dye molecule (S*) is oxidized (see equation 2) and an electron is injected into the conduction band of the semiconductor. Electrons can now move freely as the semiconductor is conductive at this energy level.

$$S^{*} \longrightarrow S^{+} + e^{-}$$

(Eq.2)

Electrons are then transported to the current collector of the anode via diffusion processes. An electrical load can be powered if connected.

STEP 3: The oxidized dye molecule (S+) is again regenerated by electron donation from the iodide in the electrolyte (see equation 3).

$$S^{+} + \frac{3}{2}I^{-} \longrightarrow S + \frac{1}{2}I_3^{-}$$

(Eq.3)

STEP 4: In return, iodide is regenerated by reduction of triiodine on the cathode (see equation 4).

$$\frac{1}{2}I_3^{-} + e^{-} \longrightarrow \frac{3}{2}I^{-}$$

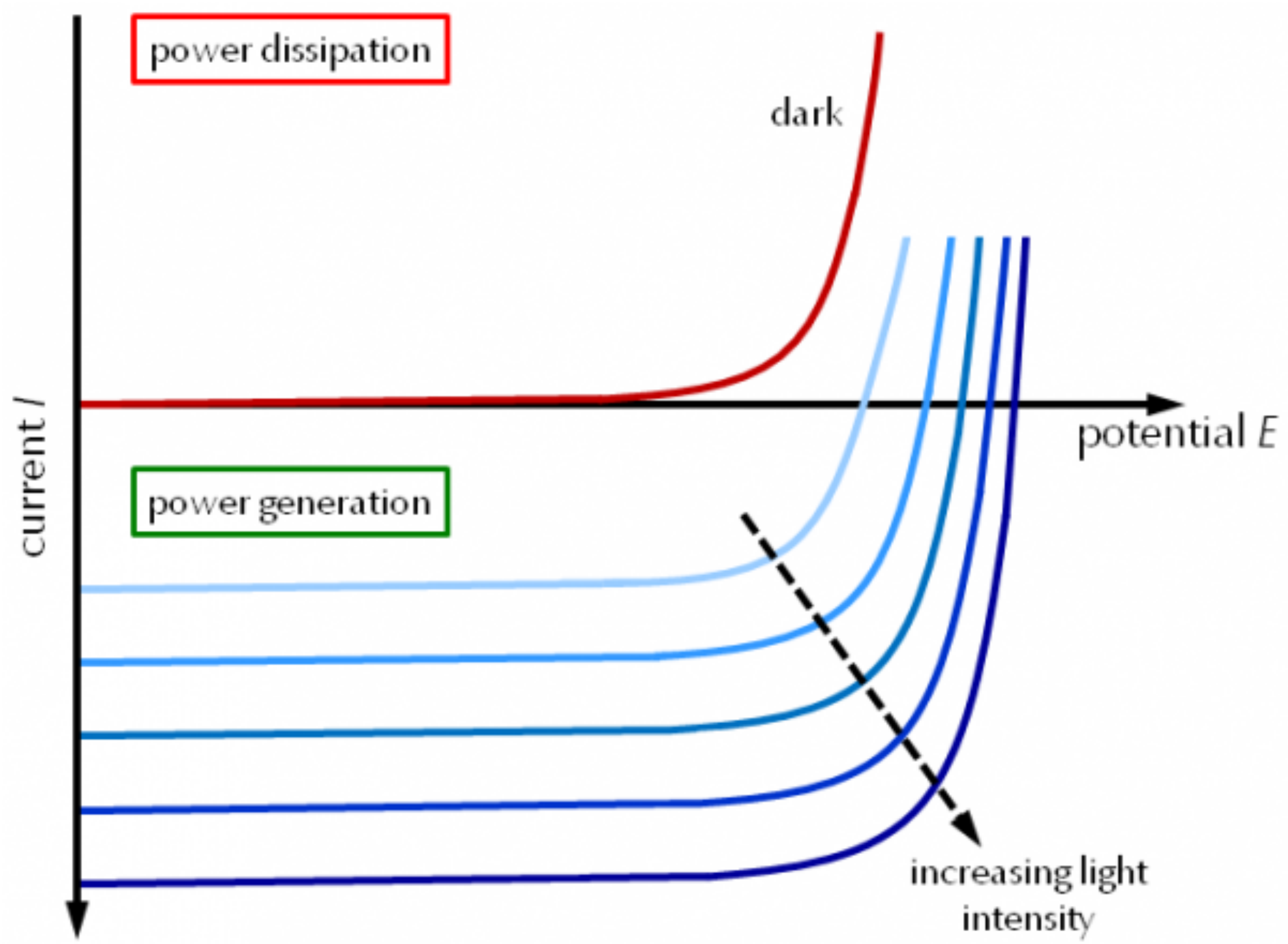
(Eq.4)

2.1.3 Important parameters

A solar cell generates current when light shines on it. The output current depends strongly on the potential of the cell as well as intensity of the incident light. Current-potential curves (also called I-V curves) illustrate the relationship.

Similar to standard cyclic-voltammetry experiments, a potential E is applied and swept between an initial and final potential. The current I of the cell is measured. In addition, a light source with a constant intensity is focused on the solar cell to generate power.

Figure 2.3 shows a typical I-V curve of a solar cell for increasing light intensities and when no light is present.



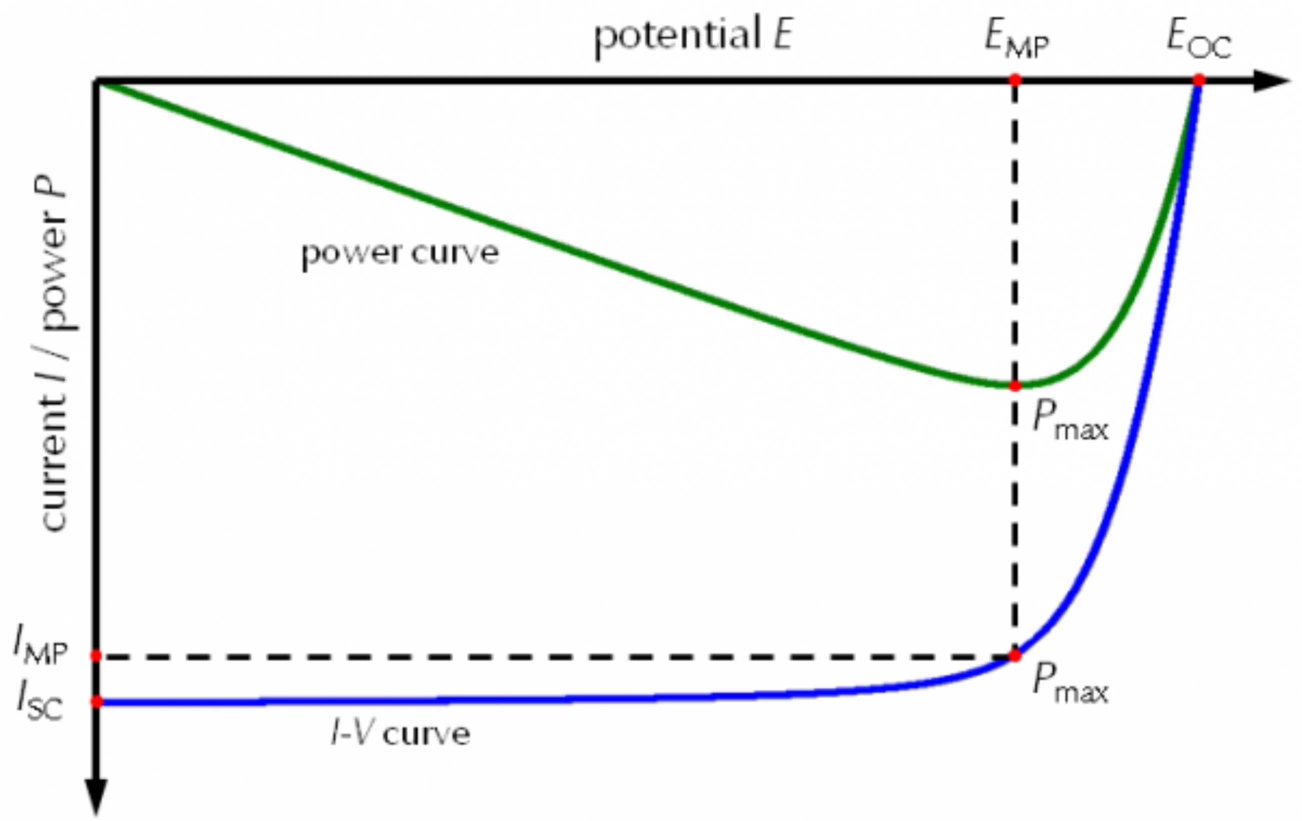
FET 2.3: Schematic diagram of I-V curves with and without light. [2]

A dye solar cell behaves like a diode when no light is present. No current is generated and energy is needed to power the cell.

The I-V curves shift further down (towards higher current) when light is focused on a DSC. The solar cell generates now current which increases with increasing light intensities.

Current flux is nearly constant at lower potentials. It reaches its maximum when the potential is zero. The generated current decreases with increasing potential. It is zero at the open-circuit potential. Above this potential, an external bias voltage is needed to power the cell. The cell can get damaged at excessively high values.

Several parameters can be derived from I-V curves which are discussed in the following sections. Figure 2.4 shows a schematic overview of an I-V curve including parameters.



FET 2.4: Schematic I V curve and power curve of a solar cell. [2]

2.1.4 Short circuit Current

The short circuit current I_{SO} is the highest current that can be drawn from a solar cell. The cell voltage is at this point zero. Hence the generated power is also zero.

$$I_{SC} = I_{max} = I(E = 0)$$

(Eq.5)

The short circuit current increases with increasing light intensity.

2.1.5 Open circuit Potential

The open circuit potential V_{OC} is the highest voltage of a solar cell at a given light intensity. It is also the potential where current flow through a solar cell is zero.

$$V_{OC} = V_{max} = V(I = 0)$$
(Eq.6)

V_{OC} is increasing with increasing light intensity.

2.1.6 Power

The generated power P of a solar cell can be calculated by the following formula:

$$P = E \cdot I$$

(Eq.7)

The calculated power can be also plotted versus the applied potential (see Figure 2.4). The resulting power curve exhibits a power maximum P_{max}.

2.1.7 Fill Factor

The Fill factor (FF) is an important parameter to specify the overall capabilities of a cell. It describes the quality and idealness of a solar cell.

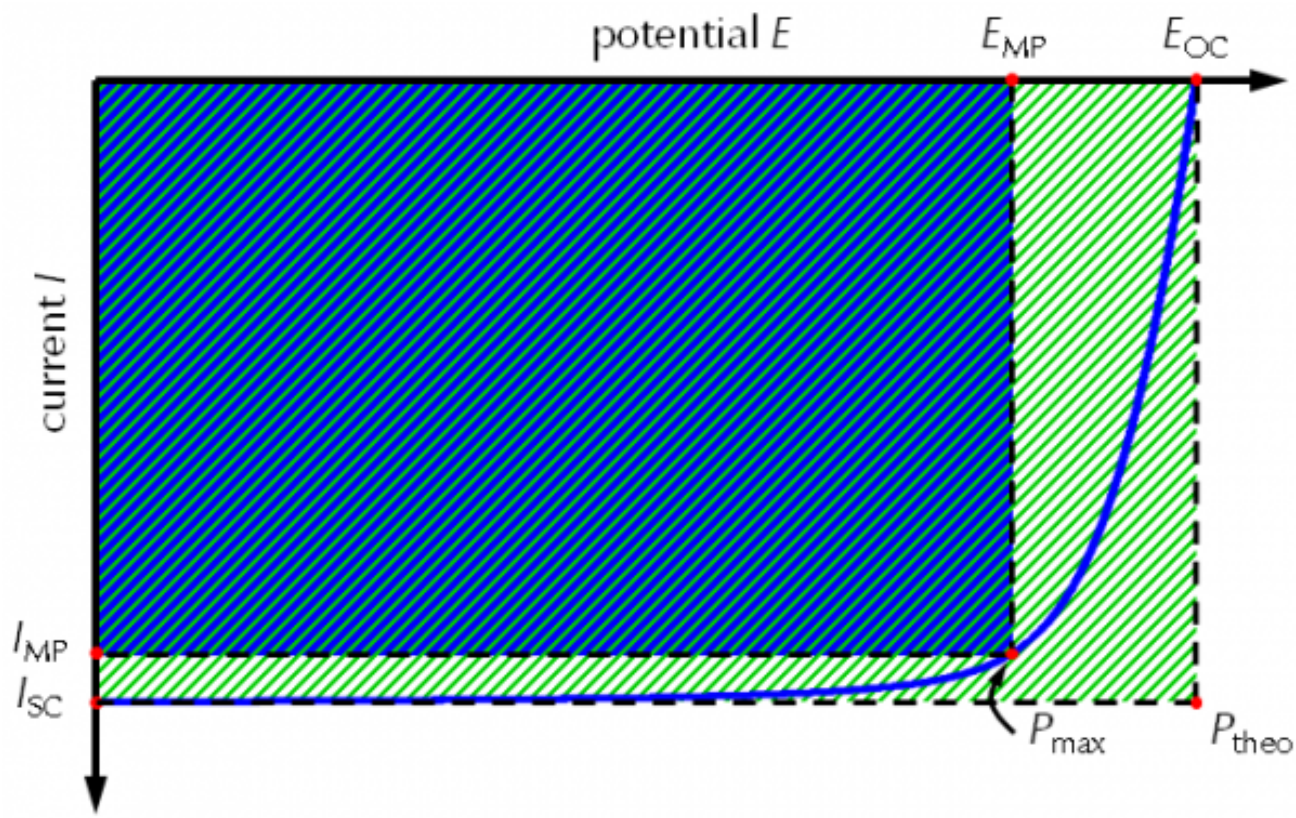
The Fill factor is the ratio of maximum generated power P_{max} to theoretical power maximum P_{theo} of a solar cell. The general formula for the Fill Factor is:

$$\mathrm{FF} = \frac{P_{\max}}{P_{theo}} = \frac{E_{MP} \cdot I_{MP}}{E_{OC} \cdot I_{SC}}$$

(Eq.8)

E_{MP} and I_{MP} are potential and current of the I V curve where the generated power is at the maximum.

The Fill factor can be also represented by rectangles in an I-V curve. Figure 2.5 shows a schematic illustration.



FET 2.5: Graphical illustration of the Fill factor. [2]

In the ideal case, an I-V curve is a rectangle (green area). The power maximum is at E_{OC} and I_{OC} and the Fill factor is one.

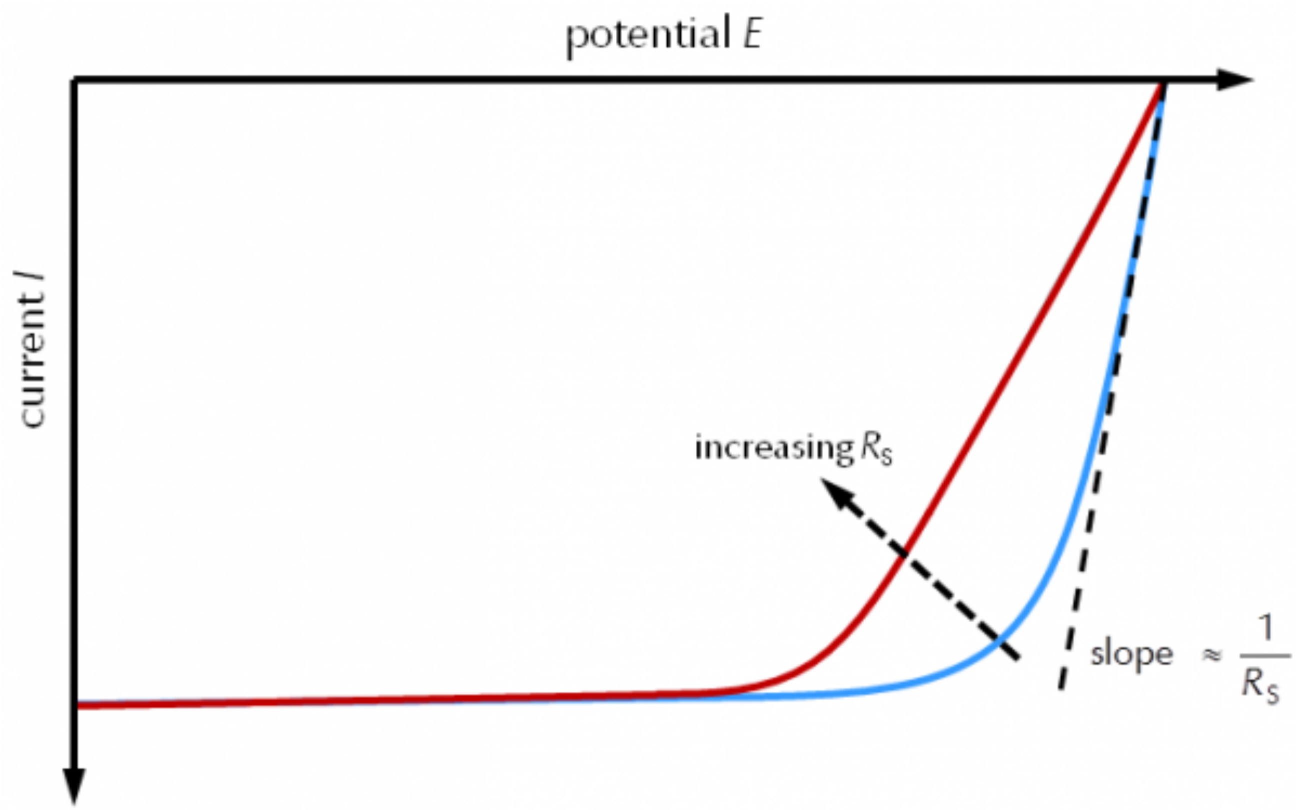
However, non ideal conditions caused by parasitic effects decrease the power maximum and the I-V curve rounds off. The resulting true area which represents the power maximum (blue rectangle) is smaller. It is covered by the potential E_{MP} and current I_{MP}.

Note that the Fill Factor is not equal to the efficiency of a solar cell.

2.1.8 Series and Shunt Resistance

As mentioned before, parasitic effects caused by internal resistances lead to power loss in a solar cell. These resistances can be described by a series resistance (R_S) and shunt resistance R_{SH}.

Figure 2.6 and Figure 2.7 show how both resistances affect the shape of an I-V curve.



FET 2.6: Effect of the series resistance $R_S$on the shape of an I-V curve. [2]

The series resistance R_S can be estimated by the inverse of the slope near the open circuit potential (see Figure 2.6).

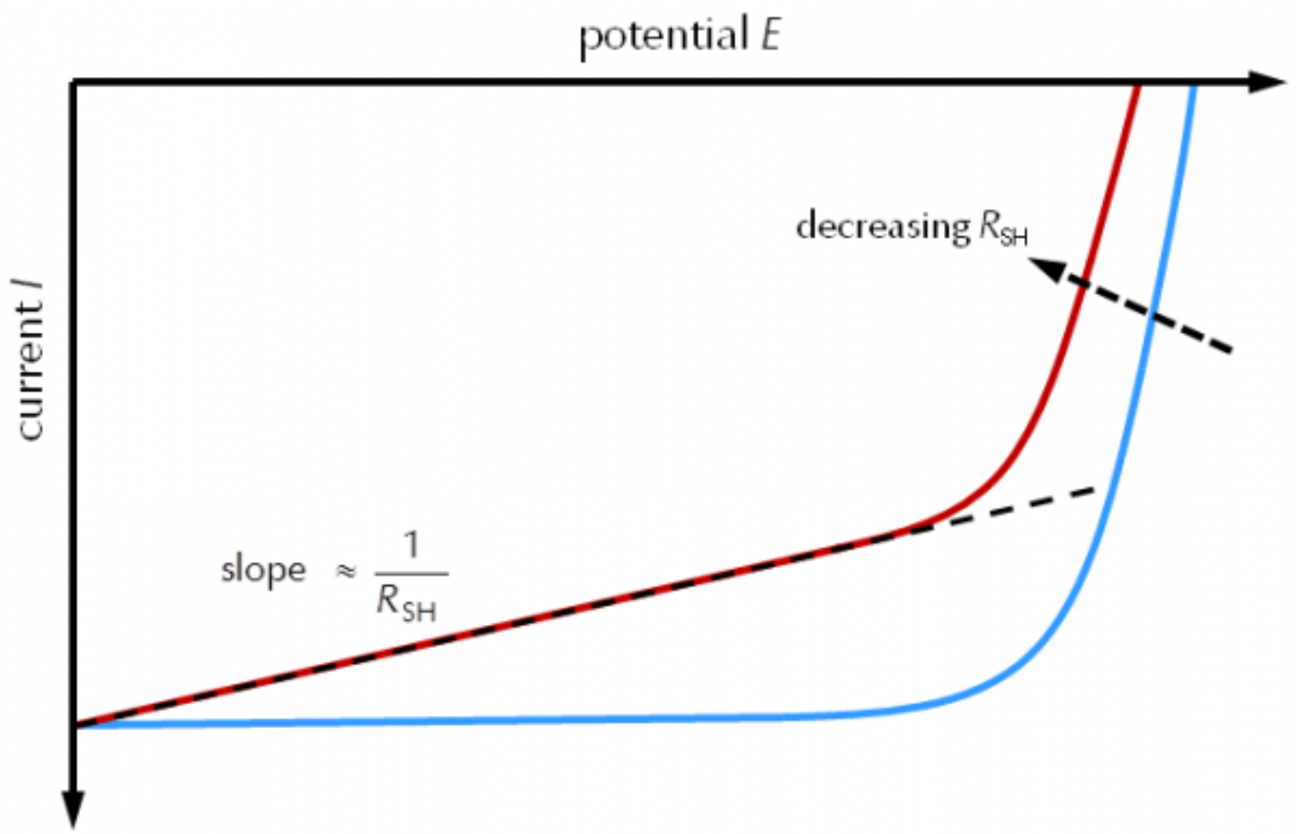
Ideally, the series resistance would be zero. However, resistances of metal contacts or bulk substrate lead to an additional voltage drop within the cell. As a result, the slope of the curve near E_{OC} decreases with increasing R_S. Hence both the area under the curve and the power maximum decrease.

Note that the open circuit potential E_{OC} is not affected by R_S because the current flow is zero. The short circuit current is also unaffected by R_S. Only very large values can lead to a reduction of I_{SC}.

R_{SH} can be estimated by the inverse slope near the short circuit current I_{SC} (see Figure 2.6). In the ideal case, this resistance is infinite so that no additional current path exists. The lower R_{SH} the more the slope of the I V curve increases near the short circuit current. This leads also to a smaller open circuit potential E_{OC}

The shunt resistance R_{SH} can be modeled by a parallel resistor. It is mainly caused by leakage current through the cell caused by impurities or defects in the manufacturing process.

Power maximum, Fill factor, and efficiency are negatively affected by small shunt resistances.



FET 2.7: Effect of the shunt resistance R_{SH} on the shape of an I V curve. [2]

2.1.9 Efficiency

The efficiency η is the ratio between maximum generated power P_{max} and electrical input power P_{in} from the light source.

$$\eta = \frac{P_{max}}{P_{in}} \cdot 100\%$$

(Eq.9)

In order to calculate the efficiency, the power of the incident light P_{in} has to be known.

Methods

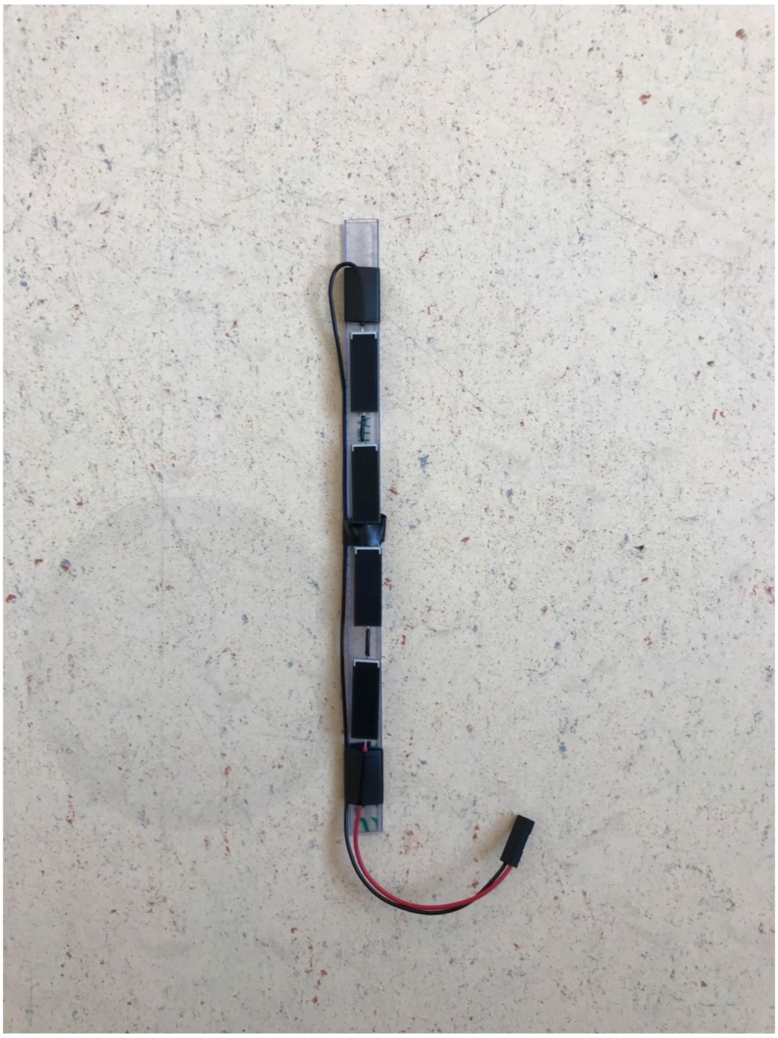
This part of the report aims to describe how the research, gathering of information and analysis are conducted throughout the project and more specifically why. The process of choosing topic and sequential approach for the thesis is presented shortly after which the main part of different applicable methodologies is explained, and specific choice of methods is motivated. At the end of the chapter the credibility of different material is discussed briefly.

3.1 CIGS solar cell

The CIGS solar cell is type of direct plasmonic solar cell which deliver < 1V. The model of solar cell used in this project is presented in Figure 3.1. A direct plasmonic solar cell converts light into electricity using plasmonic nanoparticles as the active, photovoltaic material. Plasmonic nanoparticles can absorb up to ten times as much light as other known materials.

Direct plasmonic solar cells should not be confused with plasmonic-enhanced solar cells that use plasmons to boost performance of other technologies, where the photovoltaic effect occurs in another material.

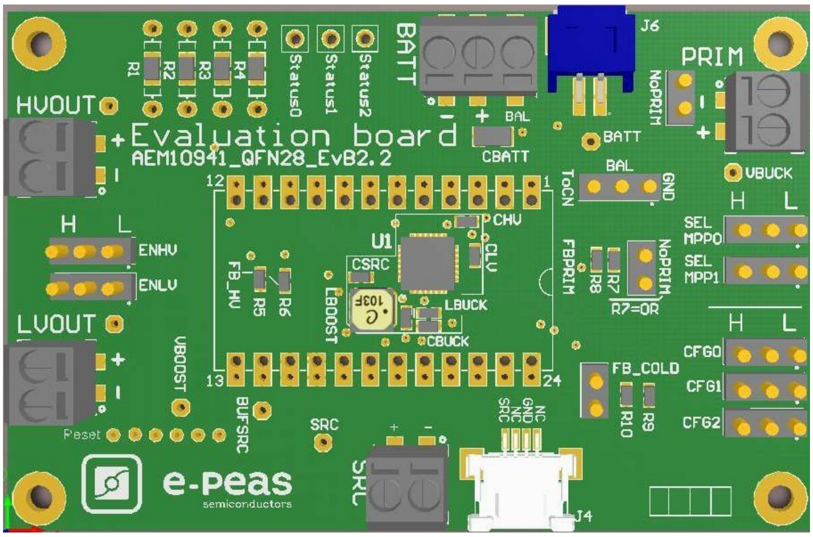
Four solar cells are connected in series. Output connections positive (red) and negative (black), will be connected further to the E-peas voltage converter.



FET 3.1: Peafowl’s solar cell

3.2 E-peas voltage converter

The AEM10941 is a full-featured energy efficient power management circuit able to charge a storage element (battery or supercapacitor, connected to BATT) from an energy source (connected to SRC) as well as to supply loads at different operating voltages through two power supplying LDO regulators (LVOUT and HVOUT). Figure 3.2 show the evaluation board for the AEM10941[4].



FET 3.2: Evaluation board for the AEM1094. [4]

The input voltage from the source to the AEM must be comprised between 50 mV and 5 V. The solar cell connects to the source in AEM board. The battery connected to BATT as energy storage. The Maximum Power Point (MPP) ratio can be configured using two configuration pins (SELMPP[1:0]). In this case the output-voltage from the AEM should be high-voltage load. From Table 3.1 two logic control pins are provided (ENLV and ENHV) to dynamically activate or deactivate the LDO regulators that sup.

FET 3.1: LDOs configurations. [4]

ENLV	ENHV	LV output	HV output
1	1	Enabled	Enabled
1	0	Enabled	Disabled
0	1	Disabled	Enabled
0	0	Disabled	Disabled

The energy storage for this model are Li-ion battery which are connected to BATT. The system needs 3.3 V like a Vhv (high voltage) from the AEM. Through three configuration pins (CFG[2:0]), the user can activate the configuration pins (CFG[2:0]) as operating for the LDO output voltages.

FET 3.2: Usage of CFG[2:0]. [4]

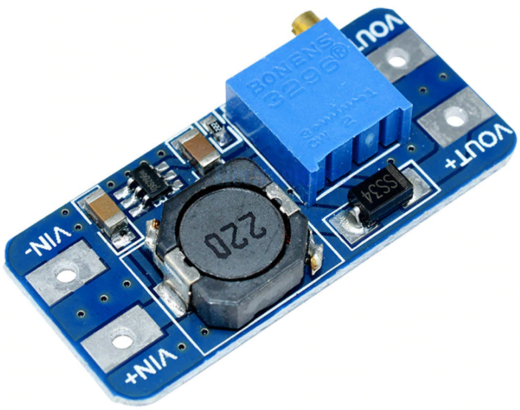
Configuration pins			Storage element threshold voltages			LDOs output voltages		Typical use
CFG[2]	CFG[1]	CFG[0]	Vovch	Vchrdy	Vovdis	Vhv	Vlv	
1	1	1	4.12 V	3.67 V	3.60 V	3.3 V	1.8 V	Li-ion battery
1	1	0	4.12 V	4.04 V	3.60 V	3.3 V	1.8 V	Solid state battery
1	0	1	4.12 V	3.67 V	3.01 V	2.5 V	1.8 V	Li-ion/NiMH battery
1	0	0	2.70 V	2.30 V	2.20 V	1.8 V	1.2 V	Single-cell supercapacitor
0	1	1	4.50 V	3.67 V	2.80 V	2.5 V	1.8 V	Dual-cell supercapacitor
0	1	0	4.50 V	3.92 V	3.60 V	3.3 V	1.8 V	Dual-cell supercapacitor
0	0	1	3.63 V	3.10 V	2.80 V	2.5 V	1.8 V	LiFePO4 battery
0	0	0	Custom mode - Programmable through R1 to R6				1.8 V	

3.3 Lithium-ion (Li-ion)

Lithium-ion batteries are the most well-known batteries and were developed and commercialised in 1991. They are known for their high cell voltages and energy density. The term "Lithium-ion batteries" actually refers to a broad spectrum of different batteries constructed of a variety of chemistries. What unites them is that lithium ions are the ions travelling through the electrolyte between the electrodes. Lithium-ion batteries are frequently used in consumer products and other lightweight applications due to their high energy density. A recent prominent area of use is in EVs and for grid application. They have an efficiency ranging between 80-95%, an energy density between 250-690Wh/dm3 and a specific energy of 100-265Wh/kg

3.4 Adjustable voltage booster

A boost converter circuit is a design intended for stepping-up or boosting a small input DC voltage levels to a desired higher output voltage level. MT3608 model is a simple boost converter circuit whose DC – DC converter works in the range 2 - 28 V giving MAX 2 A. The input voltage from E-peas are 3.3 V and the voltage booster shall convert up to 3.6 V, since the dynamic glass need the 3.6 V [5].



FET 3.2: MT3608 DC-DC Step Up Power Apply Module Booster Power Module MAX output 28V. [5]

FET 3.3: Electrical characteristics

The maximum output current	2 A
The input voltage	2 V ~ 24 V
The maximum output voltage	28 V
Efficiency	＞93%

3.5 Sensor

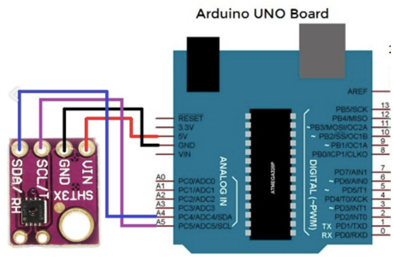
3.5.1 Temperature and humidity sensor

The new digital SHT3x humidity sensor series takes sensor technology to a new level. As the successor of the SHT2x series, it is determined to set the next industry standard in humidity sensing. The SHT3x humidity sensor series consists of a low-cost version with the SHT30 humidity sensor, a standard version with the SHT31 humidity sensor, and a high-end version with the SHT35 humidity sensor. The SHT3x humidity sensor series combines multiple functions and various interfaces (I2C, analog voltage output) with an applications-friendly, very wide operating voltage range (2.15 to 5.5 V). The SHT3x humidity sensor is available in both large and small volumes [6].

SHT3x Sensor

FET 3.3: SHT3x humidity sensor. [6]

The circuit is assembled as shown in the connection diagram in Figure 3.4.



Circuit Diagram

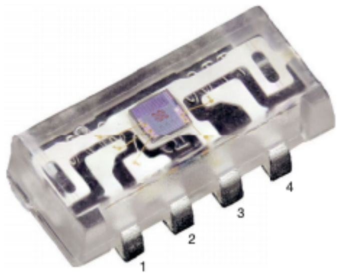
FET 3.4: Circuit Diagram

TET 3.4: Connections for SHT3x sensor with Arduino UNO

SHT3x	Arduino UNO
VIN	5V
GND	GND
SCL	A5
SCL	A4

3.5.2 Light sensor

VEML7700 is a high accuracy ambient light digital 16-bit resolution sensor. It includes a high sensitive photo diode, a low noise amplifier, a 16-bit A/D converter and supports an easy to use Gravity I^2C interface. It outputs a digital signal directly and no need for complicated calculations. This is a more acurate and easier-to-use version of the simple photoresistor which only outputs a voltage that needs to be calculated in order to obtain meaningful data. The data which is output by this sensor is directly output in Lux (Lx). When objects which are illuminated in homogeneous by get the 1 lx luminous flux in one square meter, their light intensity is 1lx. To take good advantage of the illuminant, you can add a reflector to the illuminant. Then there will be more luminous flux in some directions and it can increase the illumination of the target surface. [7]



FET 3.5: VEML7700-TR light sensor. [7]

FET 3.5: Connecting the VEML7700-TR light sensor

Pinning	VEML7700-TR	Arduino
1	SCL	A5
2	V_{DD}	3V
3	GND	GND
4	SDA	A4

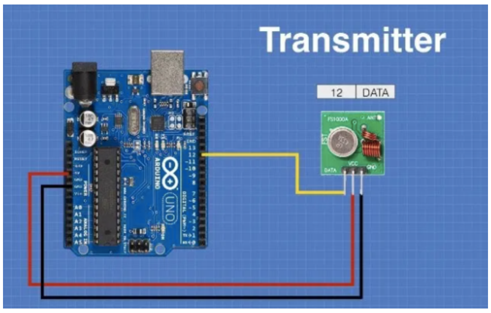
3.6 Wireless transmission

FS1000A (433 MHz/315 MHz/330 MHz RF Transmitter) & XY-MK-5V (433MHz/315MHz/330MHz RF Receiver) is a pair of low-cost radio frequency module for one-way wireless communication for Arduino, raspberry pi and other platforms. This module is used by a vast majority of electronics DIYers due to its low cost and easy implementation. The transmitter part can be operated from 3V to 12V and the maximum output can be achieved on 12V with 17cm antenna at both sides. However, the receiver requires stable 5V. These modules are available in three different frequencies which are 433MHz, 315MHz & 330MHz, so you can buy according to your frequency requirements. The max stable data transfer rate is 10kb per second.

The module only transmits one way because in this pair one is a RF transmitter and other is RF receiver. But it can be used for verity of purposes where there is not any requirement of two- way communication for example wireless temperature sensor, switching home or office appliances, and transmitting data.

3.6.1 Transmitter

The FS1000A transmitter module is very easy. For using this module you need to connect only three wires of the transmitter with one Arduino board which is shown in the Figure 3.6. The data pin of the transmitter needs to be defined in code so that it will be easy for the transmitter to talk with the receiver. In this case the pin is defined as pin 12 [8].

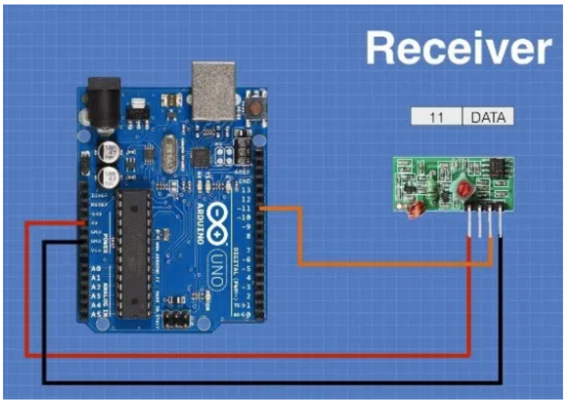


FET 3.6: FS1000A 433MHZ RF transmitter

3.6.2 Receiver

The XY-MK-5V receiver module is also very easy. For using this module you need to connect only three wires of the receiver with one Arduino board which show in the Figure 3.7. The data pin of the receiver needs to be defined in code so that it will be easy for the receiver to talk with the transmitter. In this case the data pin is defined as pin 11 [6].

FET 3.7: XY-MK-5V 433MHZ RF receiver

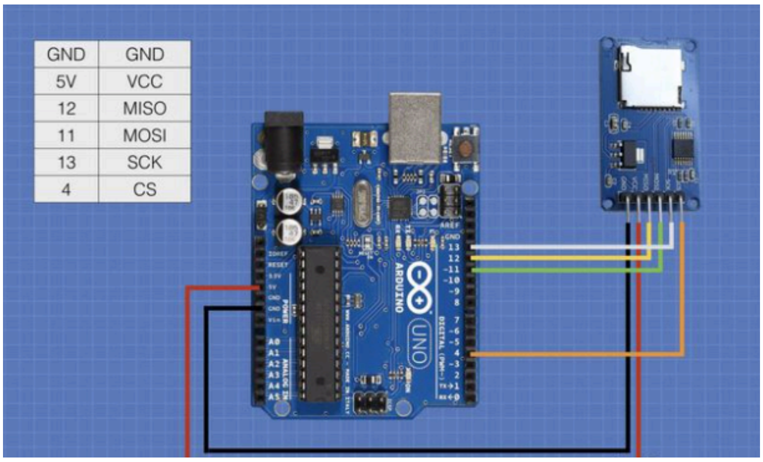


3.7 SD Card

SD Card module works with standard MicroSD Cards which operating voltage is 3.3 V. Therefore, the module has a voltage regulator and a level shifter so that we can use it with the 5 V pins of the Arduino Board [10].

FET 3.8: SD Card. [10]

The SD Card Module have six pins, two for powering the module, the V_{CC} and the GND pins, and four more pins for the SPI communication. Figure 3.9 shows how we need to connect it to the Arduino board.



FET 3.9: SD Card connect to the Arduino board

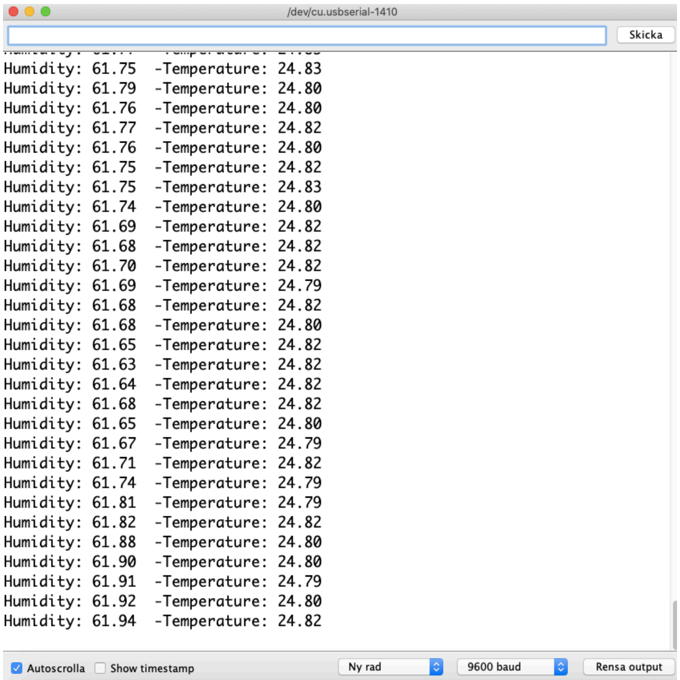
Results

Figure 4.1 shows a solar cell together with Lithium ion battery and E-peas voltage converter. The outdoor temperature was 20 °C and our solar cells deliver a constant voltage of 2.2 V.

The output voltage (HVOUT) from the AEM10941 was 3.2 V, show on digital multimeter according to table 3.2.

FET 4.1: HVOUT from the AEM10941 shows on digital multimeter.

In Figure 4.2, shows both humidity and temperature values from the SHT3x sensor by using the Arduino board.



/dev/cu.usbserial-1410

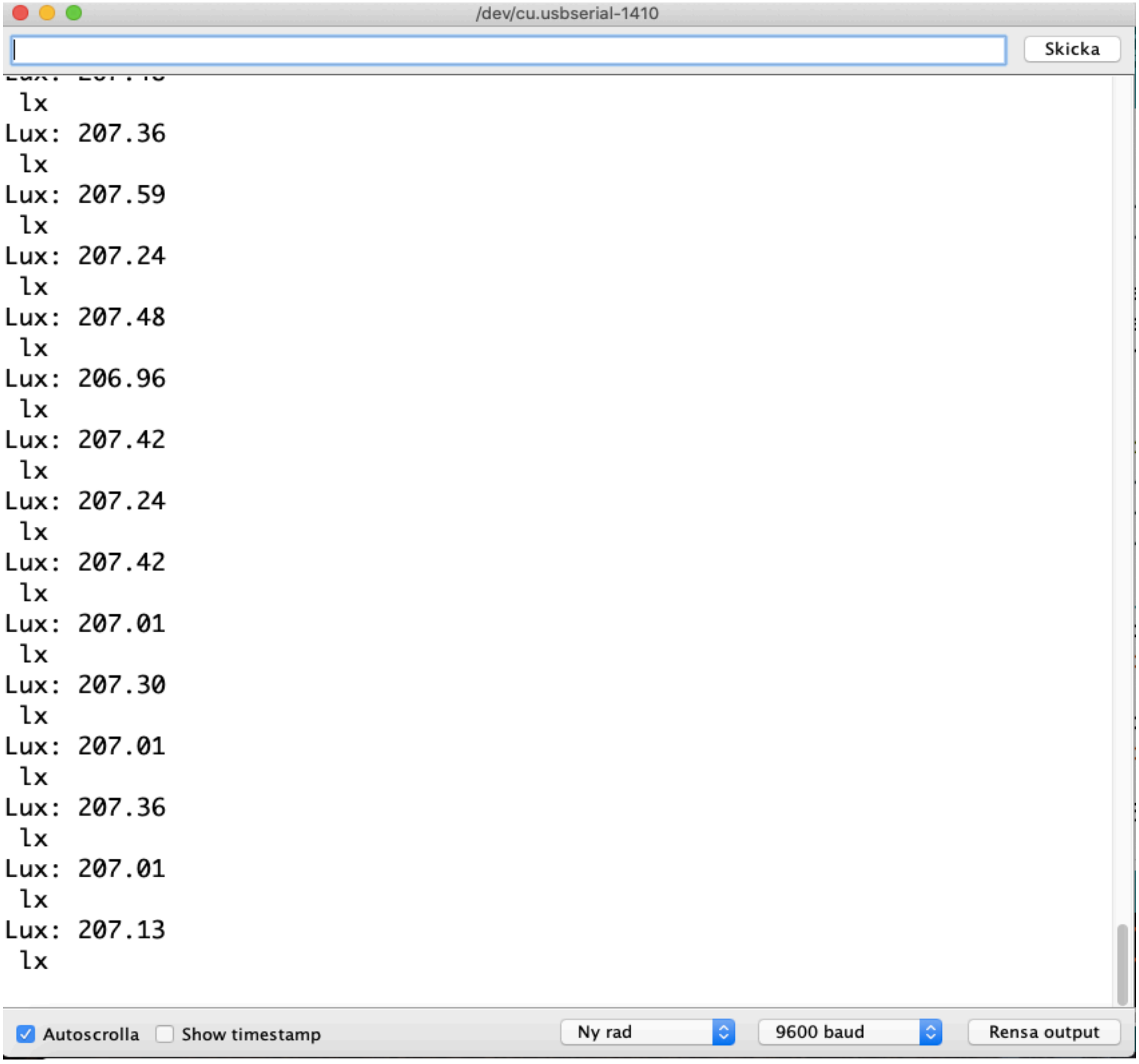
Skicka

```
Humidity: 61.75  -Temperature: 24.83
Humidity: 61.79  -Temperature: 24.80
Humidity: 61.76  -Temperature: 24.80
Humidity: 61.77  -Temperature: 24.82
Humidity: 61.76  -Temperature: 24.80
Humidity: 61.75  -Temperature: 24.82
Humidity: 61.75  -Temperature: 24.83
Humidity: 61.74  -Temperature: 24.80
Humidity: 61.69  -Temperature: 24.82
Humidity: 61.68  -Temperature: 24.82
Humidity: 61.70  -Temperature: 24.82
Humidity: 61.69  -Temperature: 24.79
Humidity: 61.68  -Temperature: 24.82
Humidity: 61.68  -Temperature: 24.80
Humidity: 61.65  -Temperature: 24.82
Humidity: 61.63  -Temperature: 24.82
Humidity: 61.64  -Temperature: 24.82
Humidity: 61.68  -Temperature: 24.82
Humidity: 61.65  -Temperature: 24.80
Humidity: 61.67  -Temperature: 24.79
Humidity: 61.71  -Temperature: 24.82
Humidity: 61.74  -Temperature: 24.79
Humidity: 61.81  -Temperature: 24.79
Humidity: 61.82  -Temperature: 24.82
Humidity: 61.88  -Temperature: 24.80
Humidity: 61.90  -Temperature: 24.80
Humidity: 61.91  -Temperature: 24.79
Humidity: 61.92  -Temperature: 24.80
Humidity: 61.94  -Temperature: 24.82
```

Autoscrolla Show timestamp Ny rad 9600 baud Rensa output

FET 4.2: Humidity and temperature values from SHT3x sensor

Figure 4.3 shows the light value of lux from the VEML7700 sensor by using the Arduino board.



FET 4.3: Light value from the VEML7700 sensor

Conclusion

Conclusions that can be drawn from this project are that the model works well and does its job in controlled conditions. All components did their job and gave reasonable results. It turned out that it is possible to implement bigger model of dynamic glass. Arduino board was a good solution to know the data the sensor gives. Local data storage recreates the historical behaviour of the shading rather good and it is possible to implement signal of the shading due to found correlations in the data analysis. The scaling was an uncertain process and it was initially unclear if it could be implemented in the method.

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