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E344 Assignment 1

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Report submitted in partial fulfilment of the requirements of the module Design (E) 344 for the degree Baccalaureus in Engineering in the Department of Electrical and Electronic Engineering at Stellenbosch University.

August 14, 2021

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23252162 Studentenommer / *Student number*	Cilliers Handtekening / *Signature*
AA. Cilliers Voorletters en van / *Initials and surname*	August 14, 2021 Datum / *Date*

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Nomenclature

Acronyms and abbreviations

PV	Photovoltaic
OC	Open Circuit
NEC	National Electrical Code
STC	Standard Test Conditions
Ah	Amp Hour
Wh	Watt Hour
CCCV	Constant Current Constant Voltage
DoD	Depth of Discharge
MOSFET	Metal Oxide Semiconductor Field Effect Transistors

Chapter 1

Solar photovoltaic cells and solar modules

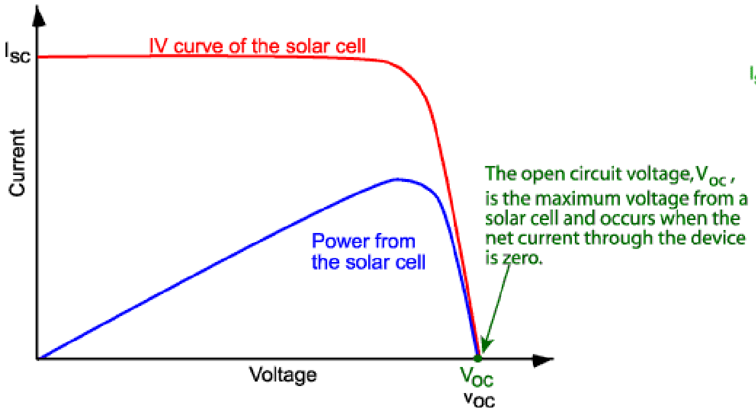
Photovoltaic (PV) technology uses a natural source of energy in the form of sunlight and coverts the sunlight into electrical energy. One PV device is called a cell, and are made from semiconductor materials such as silicon. These cells are quite small and only produce around 1-2 watts. In order to increase the power output several cells are connected together to form a module [4] [5]. Ovear the years the efficiency of solar PV modules have greatly improved, however polycrystalline PV modules which are going to be used in this project are not the most efficient type of PV module. Their efficiency is around 13-16% according to an article by Geotherm [6], however a practical study found it to be closer to 11% [7]

A PV module's performance is judged by its current–voltage (I–V) characteristic curve. As seen in figure 1.1a and figure 1.1b a few interesting points can be seen on the figures, namely the Open Circuit (OC) voltage and the Short Circuit (SC) Current. The open circuit voltage can be defined as the maximum available voltage from one solar cell when no load is connected (this occurs at 0 current). The OC voltage is useful when you want to calculate how many solar modules(panels) you can connect in series which will connect to your inverter or charge controller. SC Current is how much current the solar cell is pulling when the voltage across the cell is 0, this can be measured when the positive and negative terminals are connected directly to each other. This SC current will be the maximum amount of amps that the solar cell will produce and can be used to determine how many amps connected devices can handle by multiplying with a 1.25 times scaling factor according to National Electrical Code (NEC) 80% requirements [8]. Typically a single PV cell has an OC voltage of around 0.5V to 0.7V at room temperature (25°C) [9].

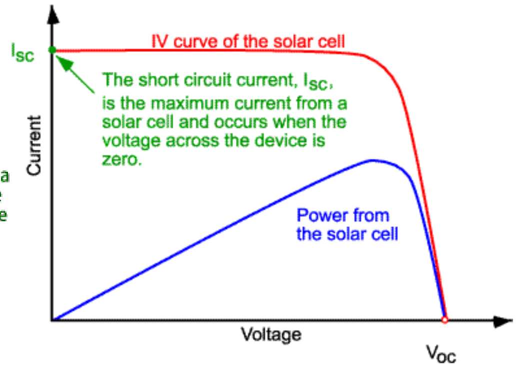
As shown in figure 1.2 the voltage increases and the current stays the same until a certain point. If you have too high a voltage the current will drastically drop, because of this there is a certain sweet spot where the optimal amount of power can be produced, this is called the maximum power point. The maximum power point is where the product of volts x amps gives the highest wattage possible. $P_{mpp} = V_{mpp} I_{mpp}$

The solar module provided to us has a OC voltage of 21.6V and a SC current of 0.34A according to the ACDC Dynamics datasheet [10]. It appears to have 36 individual solar cells.

Solar PV modules are tested at a certain set of standard conditions because voltage and current varies with temperature. This set of criteria are called the Standard Test Conditions (STC), these conditions are: the cell's temperature at 25°C, an irradiance of 1000 W/m^2 and the atmospheric density to be 1.5 . [8] At STC conditions the solar PV module provided to us has a rated power output of 5W. Table 1.1 shows some measurements of our PV module under certain test conditions.



(a) OC Voltage of Solar Cell [11]



(b) SC Current of Solar Cell [12]

Figure 1.1: OC Voltage and SC Current of Solar Cell

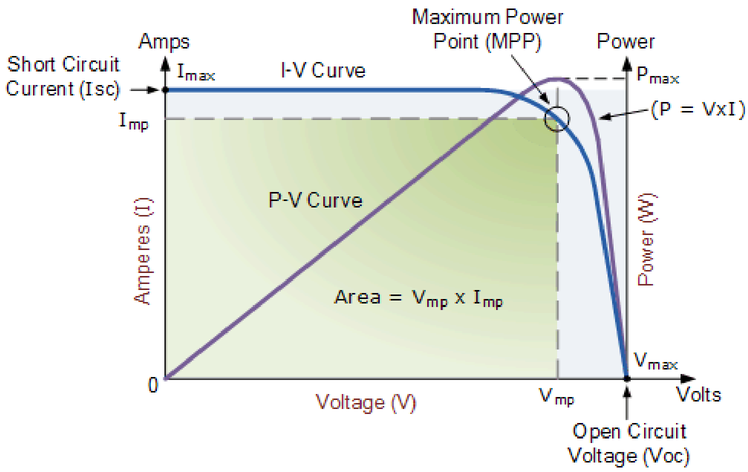


Figure 1.2: Relationship between Current and Voltage Characteristics [1]

Table 1.1: V_{OC}[V] and I_{SC} of PV module under certain test conditions

Test Condition	V_{OC}[V]	I_{SC}[mA]
Dark	0.0006	0
Upside down with sun on back	14.36	2.52
Ambient light indoors	12.46	2.32
Oblique sunlight	19.78	23.8
Perpendicular sunlight	21.8	260

Chapter 2

Lead acid batteries

Lead acid batteries are the most common battery type that is used in PV solar systems. They are low cost, have a very long lifetime and have well documented and researched technology for recharging [13]. Batteries are given a rating based on the nominal voltage of the battery, in the case of the lead acid battery provided to us it is rated at 6V. A lead acid battery is constructed of a few individual cells connected in series. The nominal voltage of a single cell is 2V, thus our battery has a total of 3 cells. The most common way to measure the storage capacity of a battery is in amp hours (Ah), which is define as the total number of hours at which a battery can provide the same amount of current equal to the discharge rate at the nominal voltage of the battery [14]. However, there is another measure called watt hour (Wh), which is determined by multiplying the Ah capacity with the nominal voltage of the battery. Our battery has an advertised capacity of 4Ah, thus the expected Wh capacity is $4Ah \times 6V = 24Wh$. This rated capacity is rated according to discharge rate and temperature of the specific battery, because the capacity is greatly affected by the discharge rate and temperature of the battery. As shown in figure 2.1 we can see that the battery capacity falls by roughly 1% per degree when the temperature of the battery is below 20°. Too high temperatures are not good for the battery either as this can make the battery age faster or self-discharge [2].

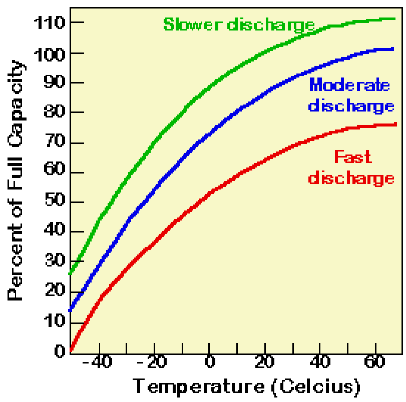


Figure 2.1: Relationship between Battery Capacity, Temperature and Discharge Rate [2]

Testing the OC voltage of the lead acid battery provided to us gives a result of 6.39V, if a load is connected to the battery, the battery will begin to discharge and the voltage of the battery will slowly begin to drop. However there will also be an instantaneous drop in voltage across the terminals of the battery, this is due to the internal resistance of the battery. Internal resistance is the resistance on the inside of the battery and determines the maximum discharge current of a battery [15].

2.1. Charging

Lead acid batteries are charged using the constant current constant voltage (CCCV) charge method. With this method the battery is charged as shown in figure 2.2 in 3 stages: constant current charge, topping charge and float charge. The constant current charge is where the current is kept at a constant rate and the main portion (70%) of the charging is done and the voltage rises to the peak voltage. The topping charge stage slowly decreases the current, but the voltage stays at the same level. The float charge lower the voltage to the float charge level in order to compensate for the loss caused by self-discharge. The battery is considered fully charged when the current drops below a certain set level (around 3-5% of the Ah rating), for our battery the current drawn would be around 40mA when the battery is fully charged. [3]. According to the datasheet provided by RS Pro [16] the maximum constant current rate at which our battery should be charged is 1.2A when using the constant voltage method. Our battery is fully charged at a float voltage of between 6.75V and 6.9V.

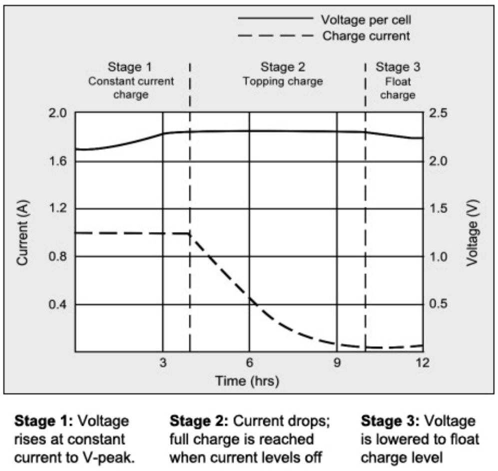


Figure 2.2: Charge States of Lead Acid Battery [3]

2.2. Discharging

After being charged the lead acid battery is now ready to be discharged,however there are some important points to consider about discharging a lead acid battery. The amount that a battery has been discharged is measured by the depth of discharge (DoD), which is expressed as a percentage relative to the total capacity of the battery [2]. Discharging a battery to 100% DoD is not recommended as this will decrease the lifetime of the battery [17]. The recommended DoD for longevity is determined by whether your battery is a shallow-cycle or deep-cycle battery. A shallow-cycle battery like ours will get the most cycles with a DoD of 50%. According to the datasheet provided by RS Pro [16] the maximum burst discharge current that our battery can provide is 60A for 5s. If a load resistor was added it would slowly start discharging the battery. The terminal voltage of our battery is 6.35V after 1 hour at 0.05C discharge rate, 6.05V after 4 minutes at 1C discharge rate, 5.45V after 20 hours at 0.05C , and it would take around 11 hours for the battery to reach 2V per cell if it uses 200mA. At 5.4V (1.8V per cell) our battery would be considered flat without affecting longevity.

Chapter 3

High-side switching circuit

3.1. Intro

Metal Oxide Semiconductor Field Effect Transistors (MOSFET) are a voltage controlled field effect transistor. The gate terminal is isolated from the main current carrying channel between the drain and source, as no current flows into the gate terminal [].Enhancement type MOSFETs requires a voltage across the gate-source terminals in order to switch the device on. Thus, the enhancement mode MOSFET acts as a normally open switch. In an NMOS (n-channel) MOSFET the device will only switch on and allow current to flow when $V_{gs} > V_{TH}$. For a PMOS (p-channel) MOSFET the opposite is true, a negative gate-source voltage will turn the transistor on, or in other words $V_{sg} > V_{TH}$.

3.2. Design

In order to design a high-side switch that uses logic level voltages (0-5V or 0-3.3V) we need to make use of a complementary pair of PMOS and NMOS MOSFETs.Pullup resistor R1 is added to keep to p-channel MOSFET off in unkown floating voltage states. Similarly a pulldown resistor R2 is added to the gate of the n-channel MOSFET to keep it off in unknown states. Resistor R1 in figure 3.1 is also used to limit the amount of current that flows through the n-channel MOSFET. If the control voltage LoadOn is at a high of 5V the n-channel MOSFET will be turned on, thus pulling the gate of the p-channel MOSFET to ground and turning it on. According to the 2n... datasheet the maximum current that can flow through the drain-source channel is 200mA, thus the minimum resistor value for R1 can be calculated as:

$$R1_{min} = \frac{25V}{200mA}$$
$$R1_{min} = 125\Omega$$

This value was designed for extremities and is the minimum resistance value that R1 can be, I chose a value of 500Ω as a design choice.

What I expect to happen is that when the LoadOn voltage is at a low the n-channel MOSFET will be off as the turn-on condition will not have been met and thus the p-channel MOSFET will also be off. When the LoadOn voltage LoadOn is at a high of 5V the n-channel MOSFET will be turned, on thus pulling the gate of the p-channel MOSFET to ground and turning it on. This will allow current to flow through the drain-source channel of the p-channel MOSFET. Calculating the expected voltage at V_{LOAD} by using a KVL loop: $-V_{supply} - V_{DS} + V_{diode} + V_{LOAD} = 0$ we get an expected value of 24V for V_{LOAD}.

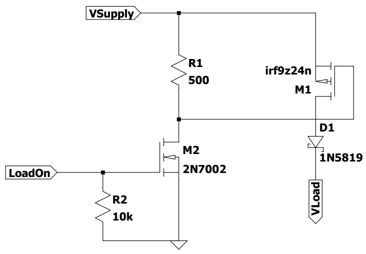


Figure 3.1: Circuit Diagram of High-Side Switch

3.3. Results

As shown in figure 3.2 we can see that the switch is switching an output voltage of 24.89V. It turns on when the external control signal is high (5V) and that it does not allow current to flow back from the load into the supply.

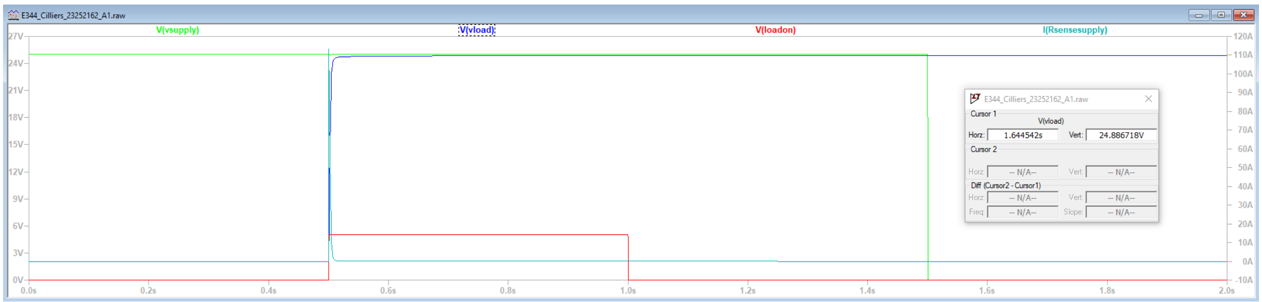


Figure 3.2: Circuit Diagram of High-Side Switch

3.4. Summary

As shown in the results section my circuit works as expected and adheres to all the requirements.

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Appendix A

Social contract

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E-design 344 Social Contract

2021

The purpose of this document is to establish commitment between the student and the organisers of E344. Beyond the commitment made here, it is not binding.

In the months preceeding the term, the lecturer (Thinus Booysen) and the Teaching Assistant (Kurt Coetzer) spent countless hours to prepare for E344 to ensure that you get your money's worth and that you are enabled to learn from the module and demonstrate and be assessed on your skills. We commit to prepare the assignments, to set the tests and assessments fairly, to be reasonably available, and to provide feedback and support as best and fast we can. We will work hard to give you the best opportunity to learn from and pass analogue electronic design E344.

I, Abraham Albertus Cilliers have registered for E344 of my own volition with the intention to learn of and be assessed on the principals of analogue electronic design. Despite the potential publication online of supplementary videos on specific topics, I acknowledge that I am expected to attend the scheduled lectures to make the most of these appointments and learning opportunities. Moreover, I realise I am expected to spend the additional requisite number of hours on E344 as specified in the yearbook.

I acknowledge that E344 is an important part of my journey to becoming a professional engineer, and that my conduct should be reflective thereof. This includes doing and submitting my own work, working hard, starting on time, and assimilating as much information as possible. It also includes showing respect towards the University's equipment, staff, and their time.

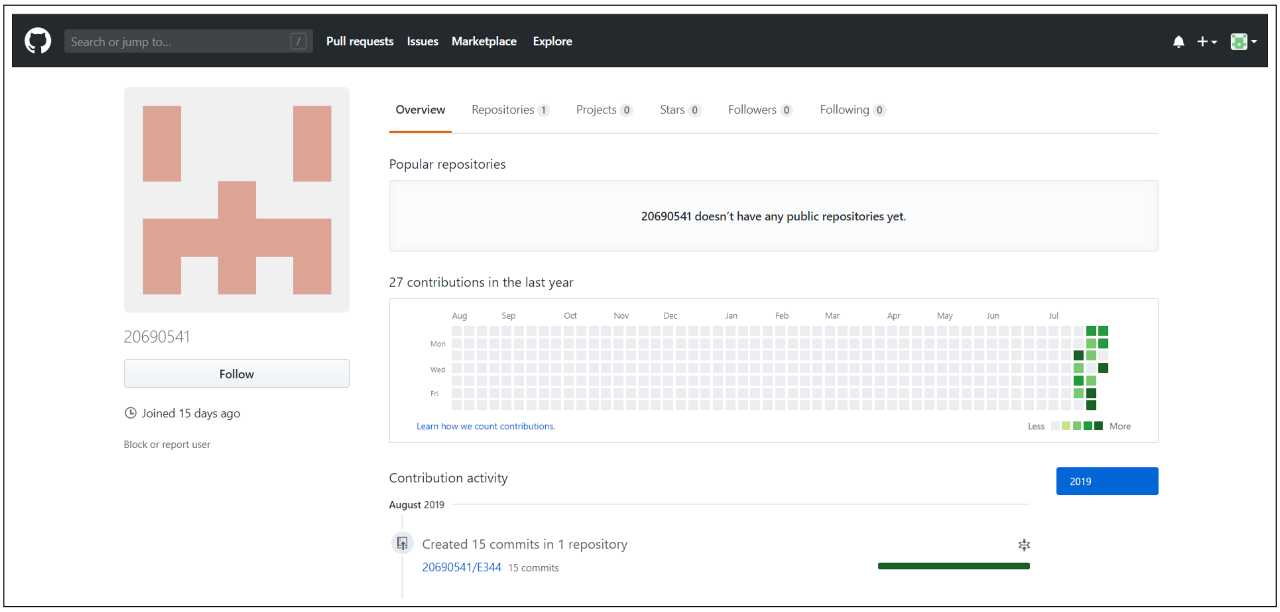
Prof. MJ Booysen	Student number: 23252162
Signature: Digitally signed by MJ BOOYSEN Date: 2021.08.04 22:12:45 +02'00'	Signature: Cilliers
Date: 4 Aug 2021	Date: 10 Aug 2021

1

Appendix B

GitHub Activity Heatmap

Take a screenshot of your github version control activity heatmap and insert here.



Appendix C

Stuff you want to include