LAB 3 – MAXIMUM POWER POINT TRACKING FOR PV SYSTEM USING CONSTANT VOLTAGE REFERENCE

Group Information

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Report Submission

Each group only requires to submit one report. Waveforms, graphical plots, calculations and answers should be laid out neatly and correctly. Marks will be lost for missing and illegible work. Submit your report via UTSOnline. Note the deadline of submission on UTSOnline. Late submission will attract a deduction of marks (5% per day after the deadline).

Declaration of Originality

The work contained in this assignment, other than that specifically attributed to another source, is that of the author(s). It is recognised that, should this declaration be found to be false, disciplinary action could be taken and the assignments of all students involved will be given zero marks. In the statement below, I have indicated the extent to which I have collaborated with other students, whom I have named.

Statement of Collaboration and Signatures

Marks

Pre-lab work	
Lab work	
Total marks	

3. Pre-Lab Work

i) Explain the working principle of the PV emulator.

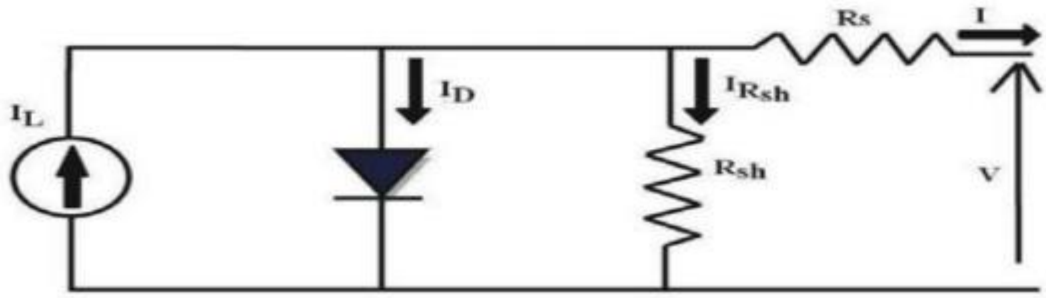


Figure 1: PV system

To understand the working of the PV emulator, we need to look back on the mathematical model of photovoltaic PV array:

$$I = I_L - I_D - I_{Rsh}. \ (1)$$

Where the diode current is represented by the formula below:

$$I_D = I_S * \left(e^{\frac{V_D}{V_T}} - 1 \right) (2)$$

Where $V_D = V_{out} - I * R_S$.(3)

$$V_T = \frac{K_B * T * A}{q}$$

A: the ideality factor of the solar cell

q = 1.6*$10^{-19}C$: the charge of the electron in Coulomn.

$K_B = 1.38 * 10^{-23} (\frac{J}{K})$: the Boltzmann constant.

T : the temperature in Kelvin

The leakage current $I_{Rsh}$is given by the equation (4)

$$I_{Rsh} = \frac{(V_{out} + I * R_S)}{R_{sh}}. \ (4)$$

Overall, we have the output current given in equation (5):

$$I = I_L - I_S * \left(e^{\frac{V_{out} - I * R_S}{\frac{K_B * T * A}{q}}} - 1 \right) - \frac{(V_{out} + I * R_S)}{R_{sh}}. \ (5)$$

As the R_{sh} has large voltage compare to R_S and does not interfere to the output voltage, thus we can reduce the equation (5) to equation (6)

$$I = I_L - I_S * \left(e^{\frac{V_{out} - I * R_S}{\frac{K_B * T * A}{q}}} - 1 \right)$$

which leave us three parameter to choose I_S, I_L, R_S. These values are obtained from data sheet or laboratory tests.

From the equation (5), we can find the power of the system:

$$P = I * V_{out}$$

Or $$P = \left(I_L - I_S * \left(e^{\frac{V_{out} - I * R_S}{\frac{K_B * T * A}{q}}} - 1\right)\right) * V_{out} \quad (6)$$

To be more understandable, we will see the pictures below

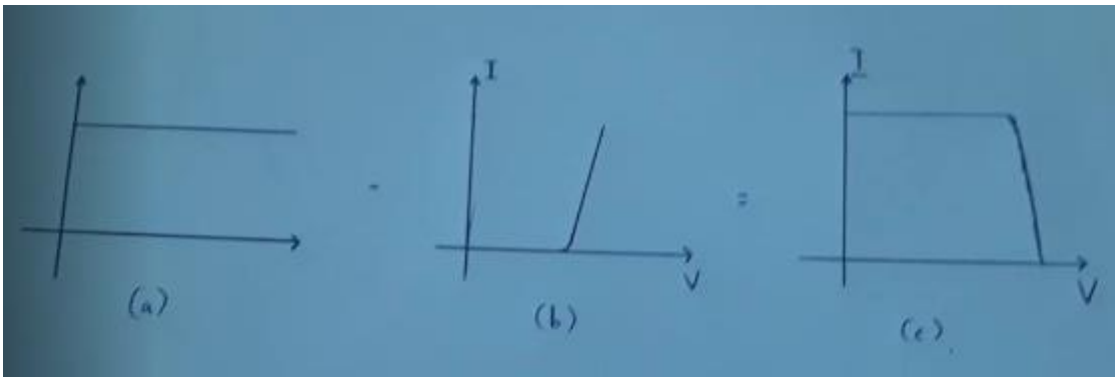


Figure 2: a: the DC current supply

b: Relationship between current and voltage on diode

c: Result of the circuit

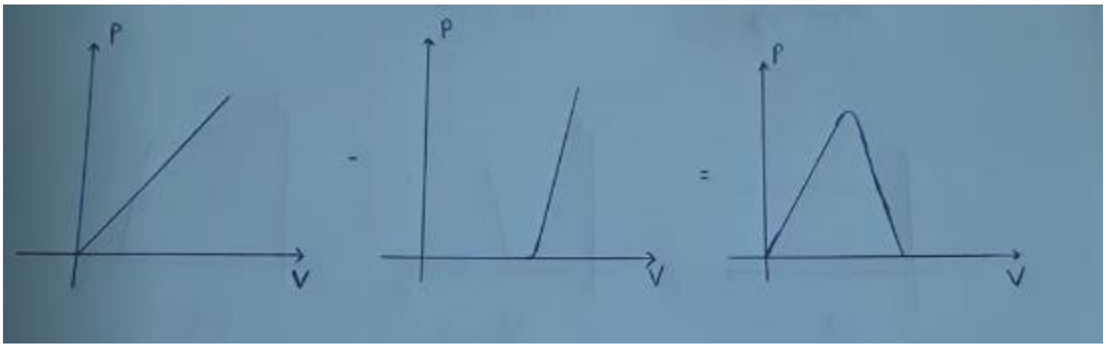


Figure 3: a: the relationship between power and voltage in power DC supply

b: Relationship between power and voltage on diode

c: Result of the circuit

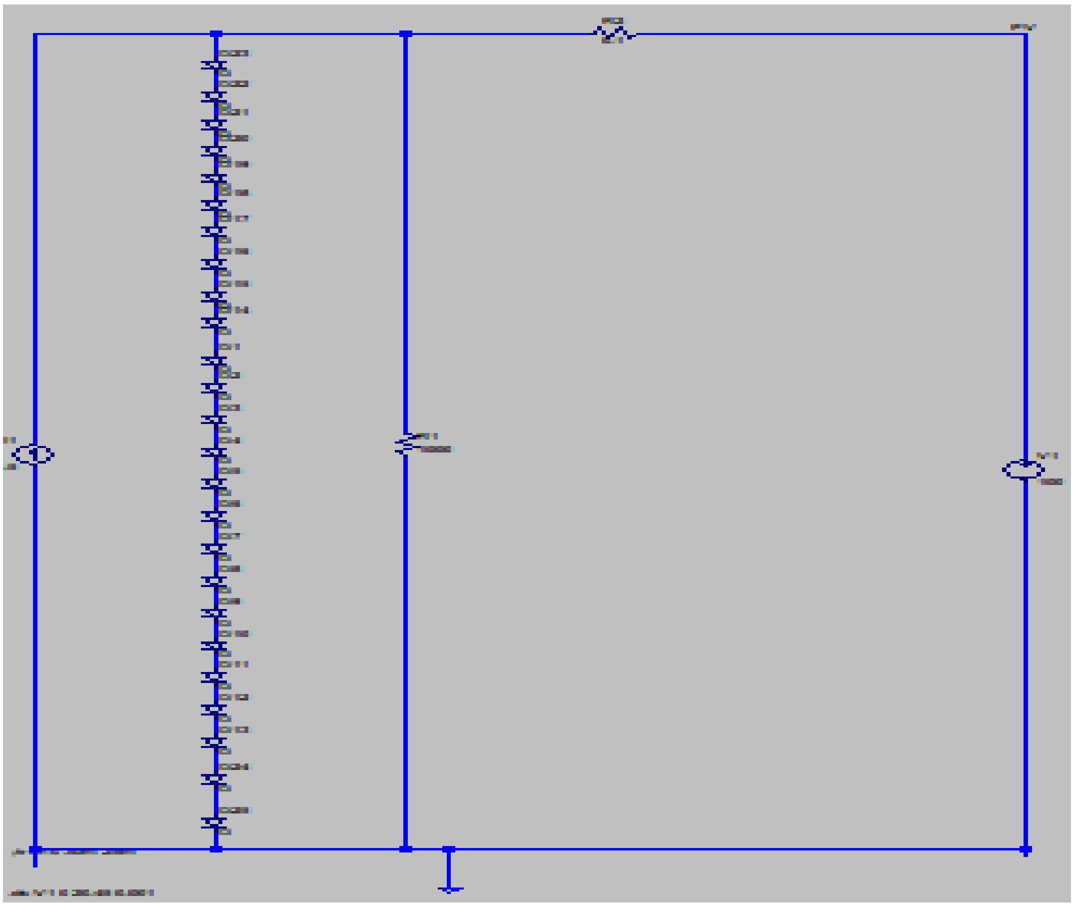


Figure 4: LTSpice PV emulator circuit

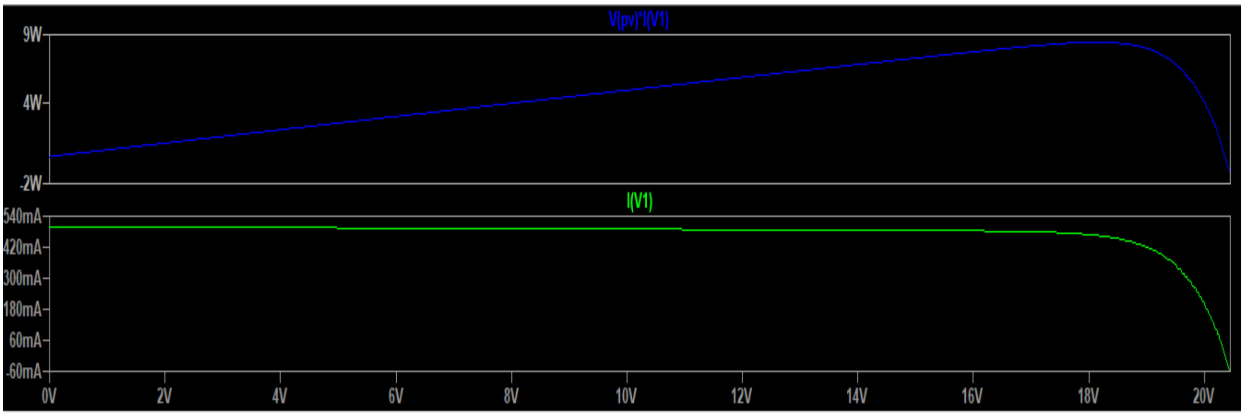


Figure 5: Result from LTSpice PV emulator in figure 4

ii) Explain how the duty cycle should change to make the PV panel voltage constant and operate at the reference voltage. For a given insolation level the PV panel voltage is not yet regulated but is located on the right hand side of the I-V curve that is away from the MPP (i.e. Point A) as shown in Fig. 2, should the duty cycle decrease or increase in order to move toward the MPP? How about when the operating point is on the left-hand side of the I-V curve further away from the MPP (i.e. Point B)?

A.

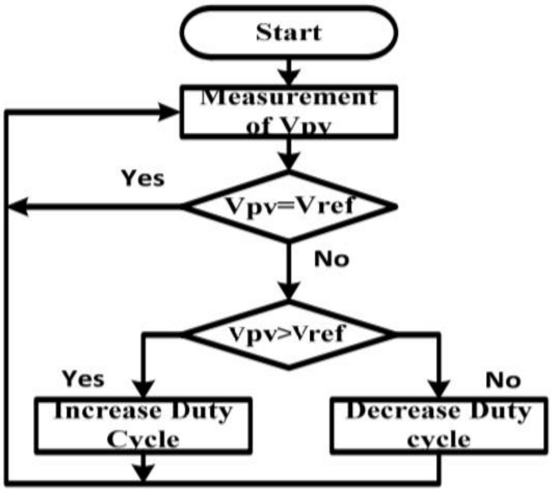


Figure 6 – Flow chart of Constant Voltage MPPT

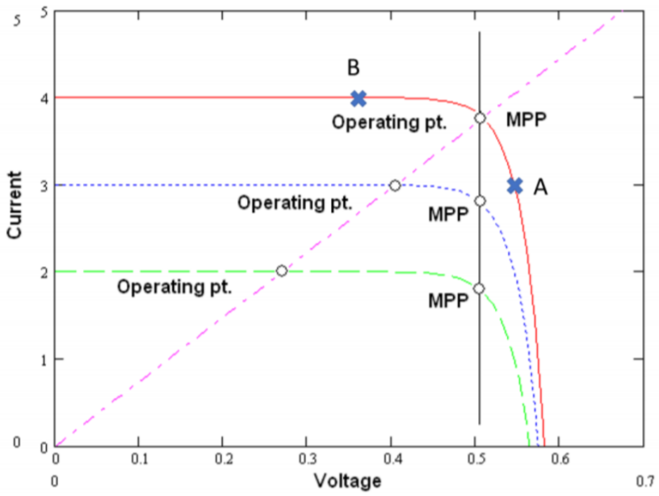
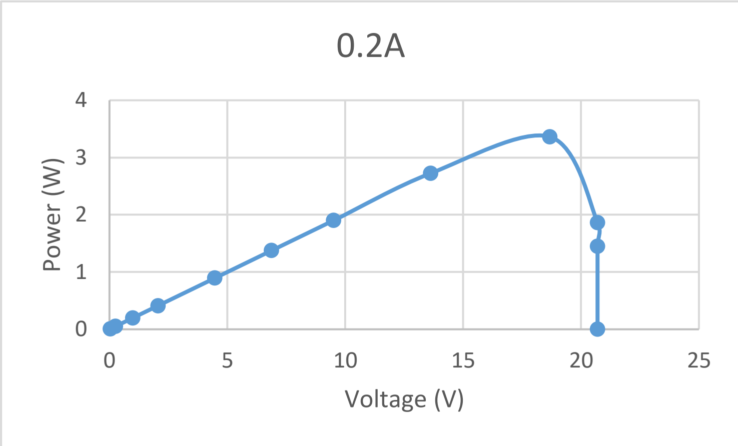


Figure 7 – Comparison of fixed resistance and constant voltage reference MPPT on single PV cell.

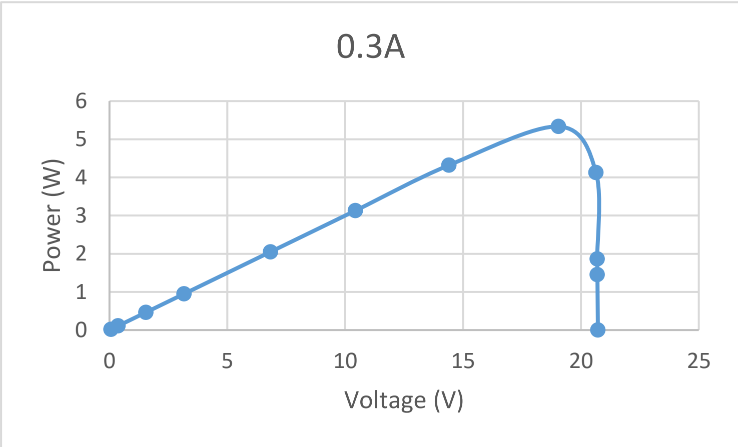
From the flow diagram above, the duty cycle will change according to what the microcontroller measures as the voltage of the PV and compare it to that of the reference voltage. In other words, if the PV voltage is greater than the reference voltage then the duty cycle will be increased in order to compensate for the value. Conversely, if the PV voltage is less than the reference voltage, the duty cycle will be decreased in order to ensure that both the PV and reference voltage are equal. With this in mind, in order to shift the PV voltage to the MPP as shown in figure 2, the duty cycle must increase in order to match the reference signal. Conversely, if the voltage operating point is to the left, the duty cycle must be increased.

5.1 PV emulator

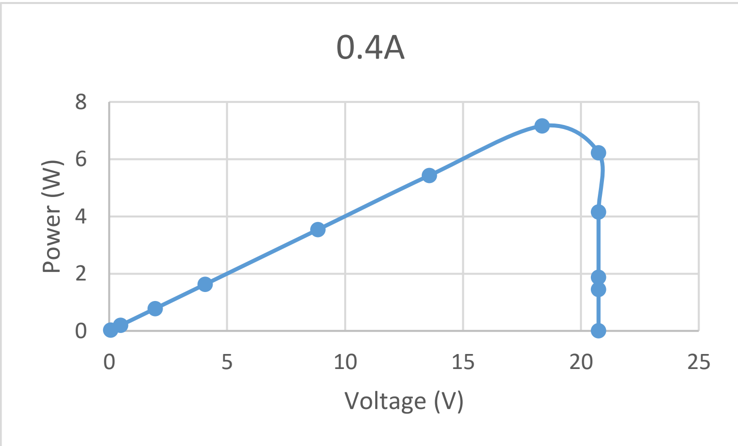
	0.2 A		
R(Ω)	I (A)	v(V)	P(W)
0	0.2	0.04	0.008
1	0.2	0.25	0.05
4.7	0.2	0.99	0.198
10	0.2	2.06	0.412
22	0.2	4.47	0.894
33	0.2	6.87	1.374
47	0.2	9.51	1.902
68	0.2	13.63	2.726
100	0.18	18.68	3.3624
220	0.09	20.7	1.863
270	0.07	20.7	1.449
O/C	0	20.7	0



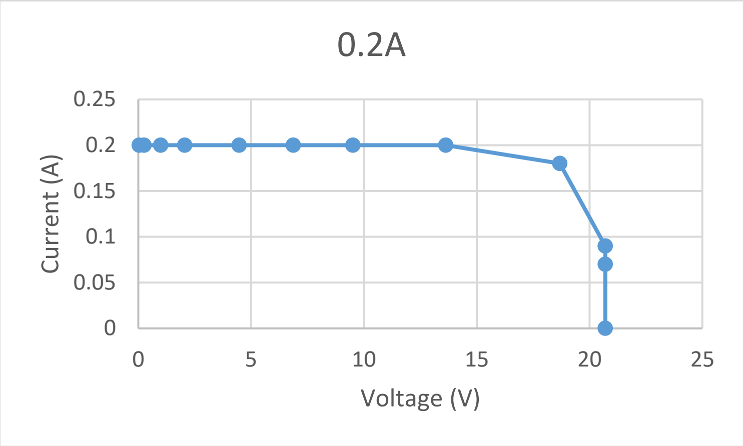
	0.3 A		
R(Ω)	I (A)	v(V)	P(W)
0	0.3	0.06	0.018
1	0.3	0.37	0.111
4.7	0.3	1.55	0.465
10	0.3	3.16	0.948
22	0.3	6.83	2.049
33	0.3	10.43	3.129
47	0.3	14.4	4.32
68	0.28	19.05	5.334
100	0.2	20.64	4.128
220	0.09	20.69	1.8621
270	0.07	20.7	1.449
O/C	0	20.72	0

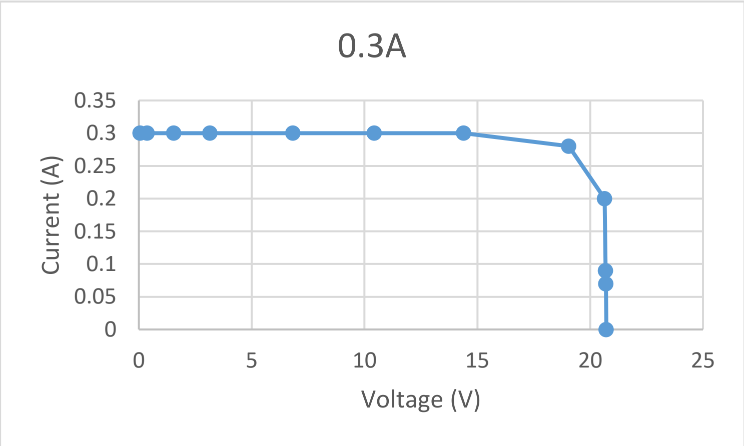


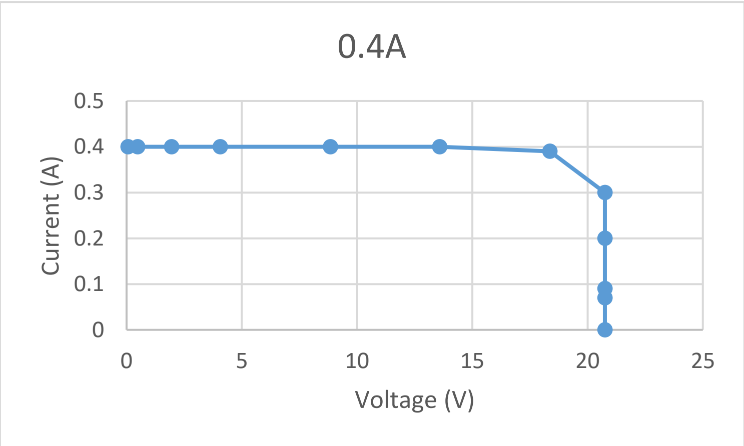
	0.4 A		
R(Ω)	I (A)	v(V)	P(W)
0	0.4	0.07	0.028
1	0.4	0.48	0.192
4.7	0.4	1.95	0.78
10	0.4	4.07	1.628
22	0.4	8.85	3.54
33	0.4	13.58	5.432
47	0.39	18.36	7.1604
68	0.3	20.75	6.225
100	0.2	20.75	4.15
220	0.09	20.75	1.8675
270	0.07	20.75	1.4525
O/C	0	20.75	0



Above are our experimental results which we got from testing the PV emulator at current limits of 0.2, 0.3 and 0.4 A respectively. Next to these tables are the graphs of our P-V curves at the corresponding current limits. From these graphs we were easily able to locate the maximum power point (MPP), which has been highlighted on each table respectively. The average of these results left us with a MPP value of roughly 18.7 V. Below you can also see the I-V curves at each of the corresponding current limits.







5.5 Testing of the Buck Converter

c) Use other channels to observe the mid-point (TP102), inductor current, and output voltage. Record the waveforms of all four channels including the PWM signal.

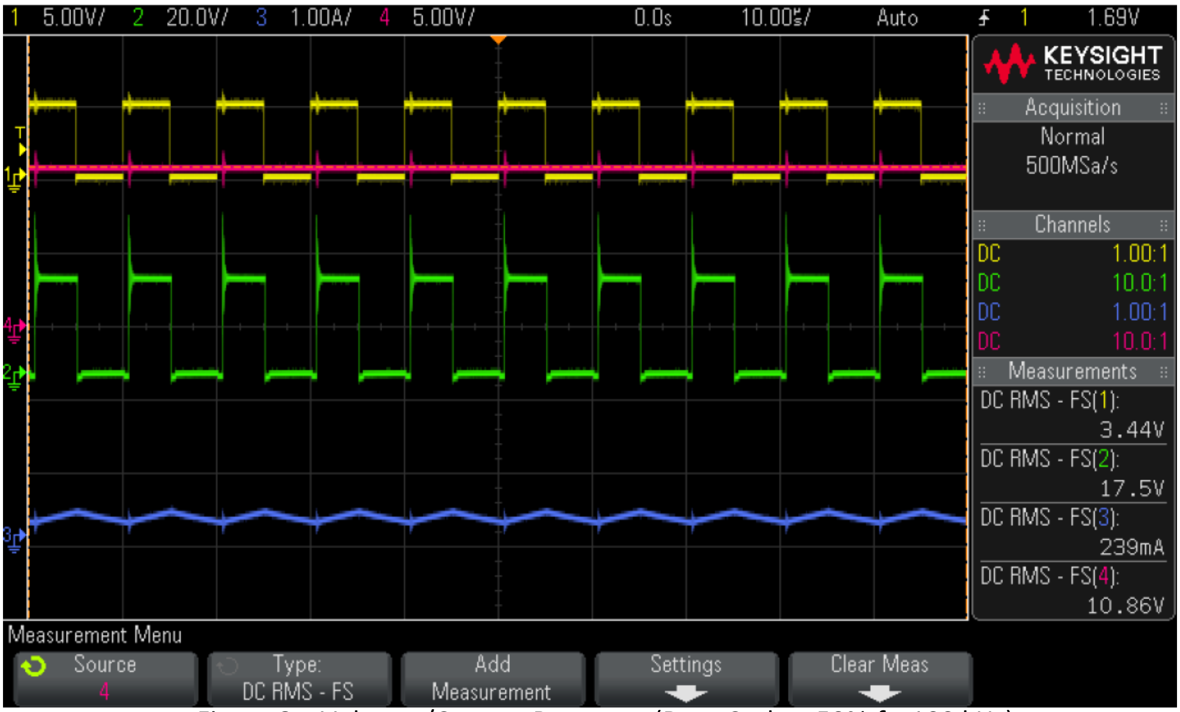


Figure 8 – Voltages/Current Response (Duty Cycle = 50% *f* = 100 kHz)

Yellow – Input Voltage
Green – Midpoint Voltage
Pink – Output Voltage
Blue – Inductor Current

5.7 Testing of Constant Voltage Reference MPPT

Below are screenshots taken from the oscilloscope as we varied the current limits on the 21V power supply between 0.4 and 0.6 A.

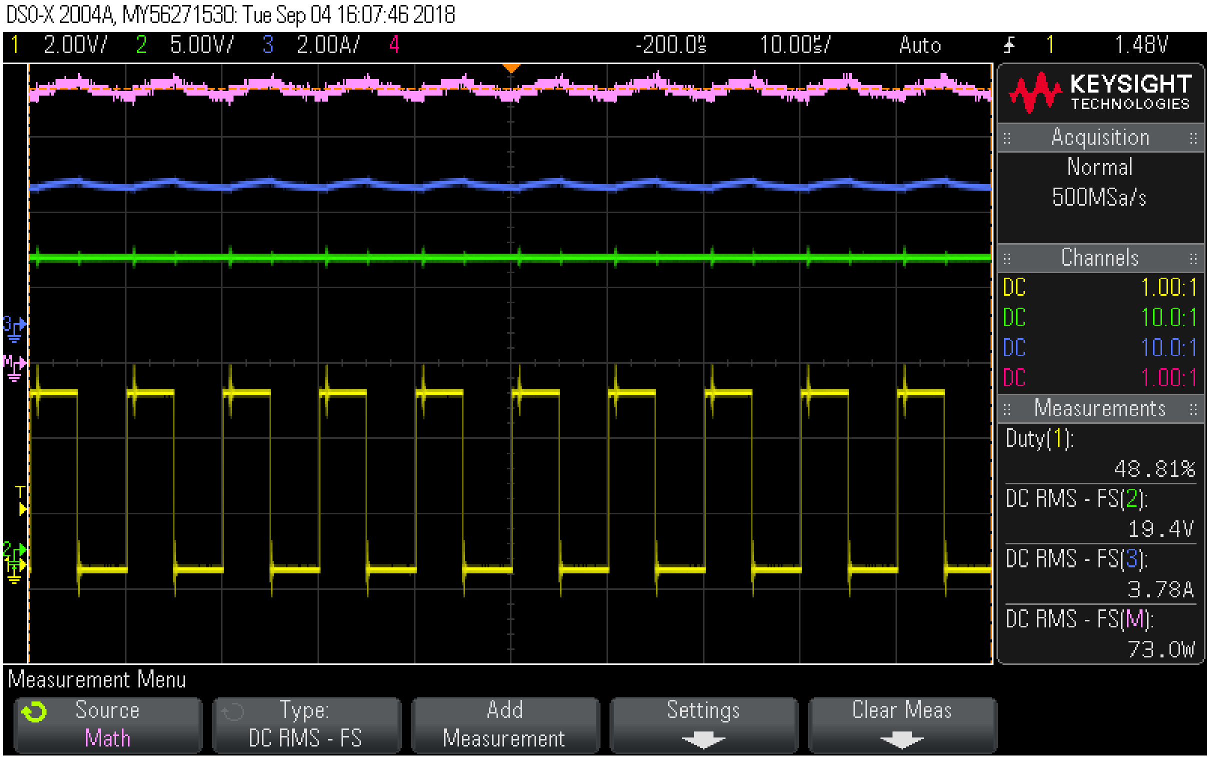


Figure 9: Readings at 0.4 A current limit

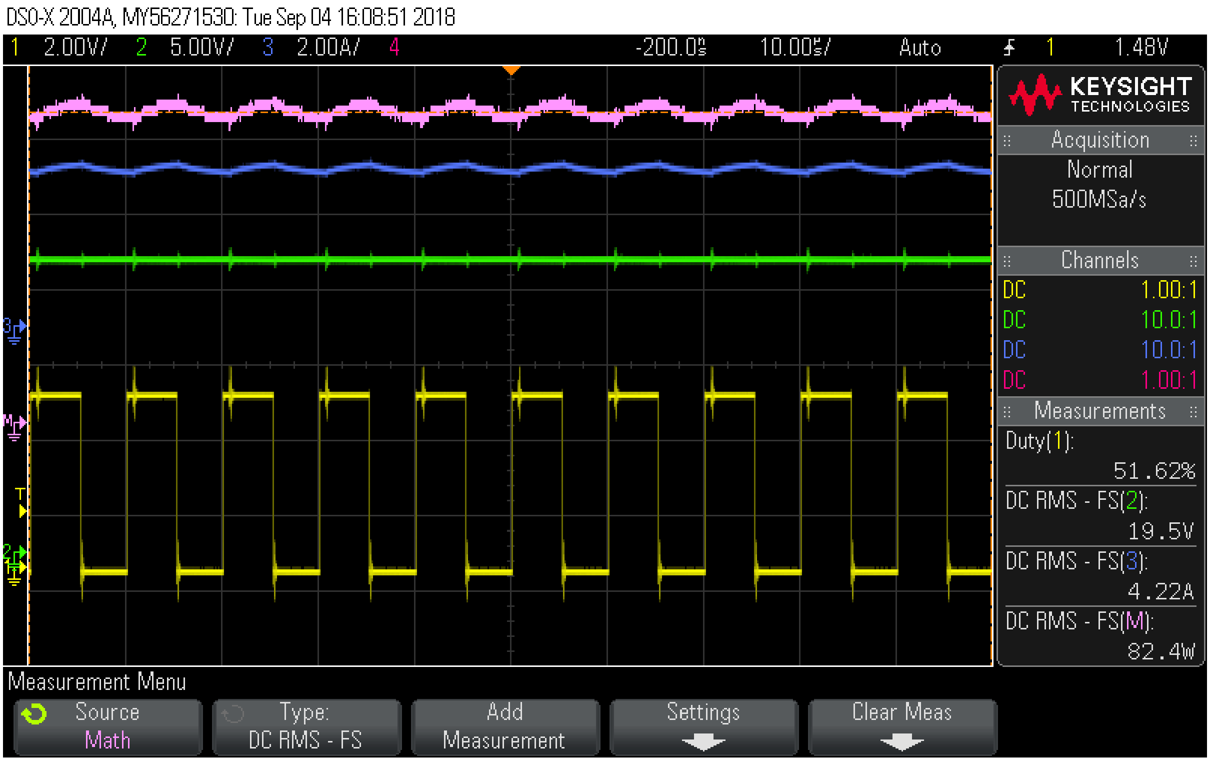


Figure 10: Readings at 0.45 A current limit

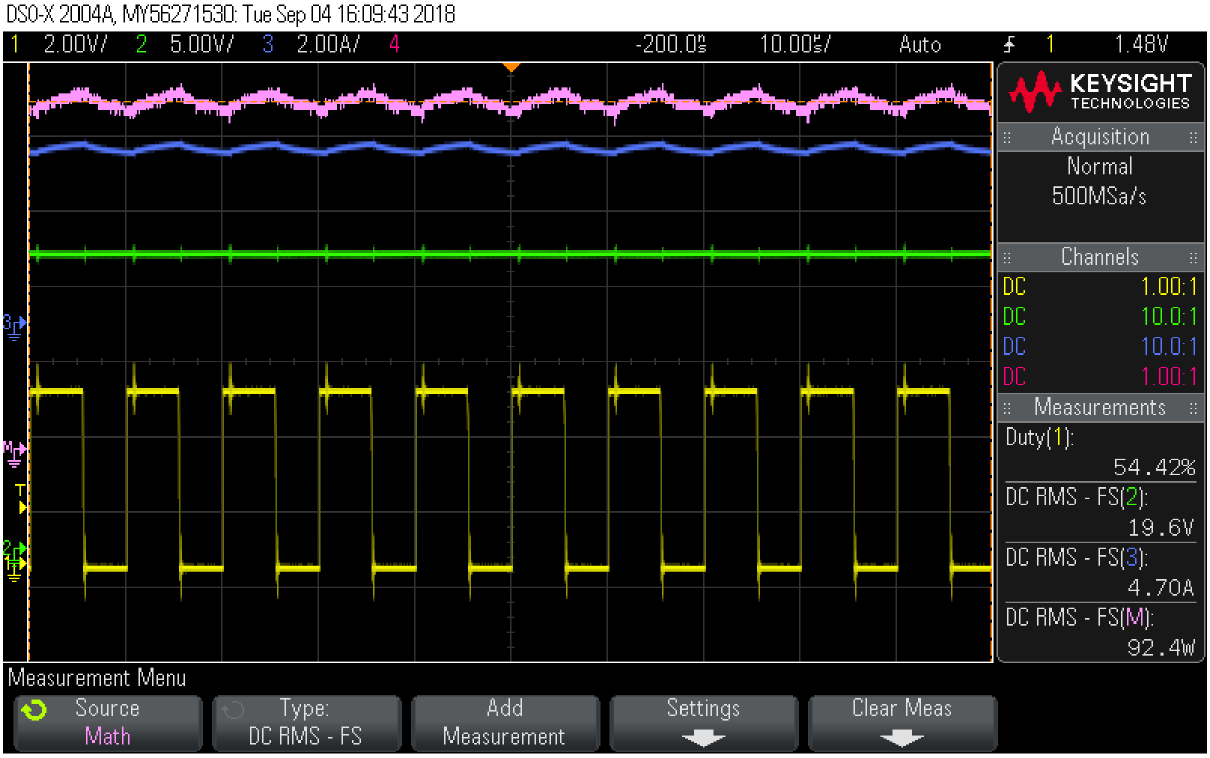


Figure 11: Readings at 0.5 A current limit

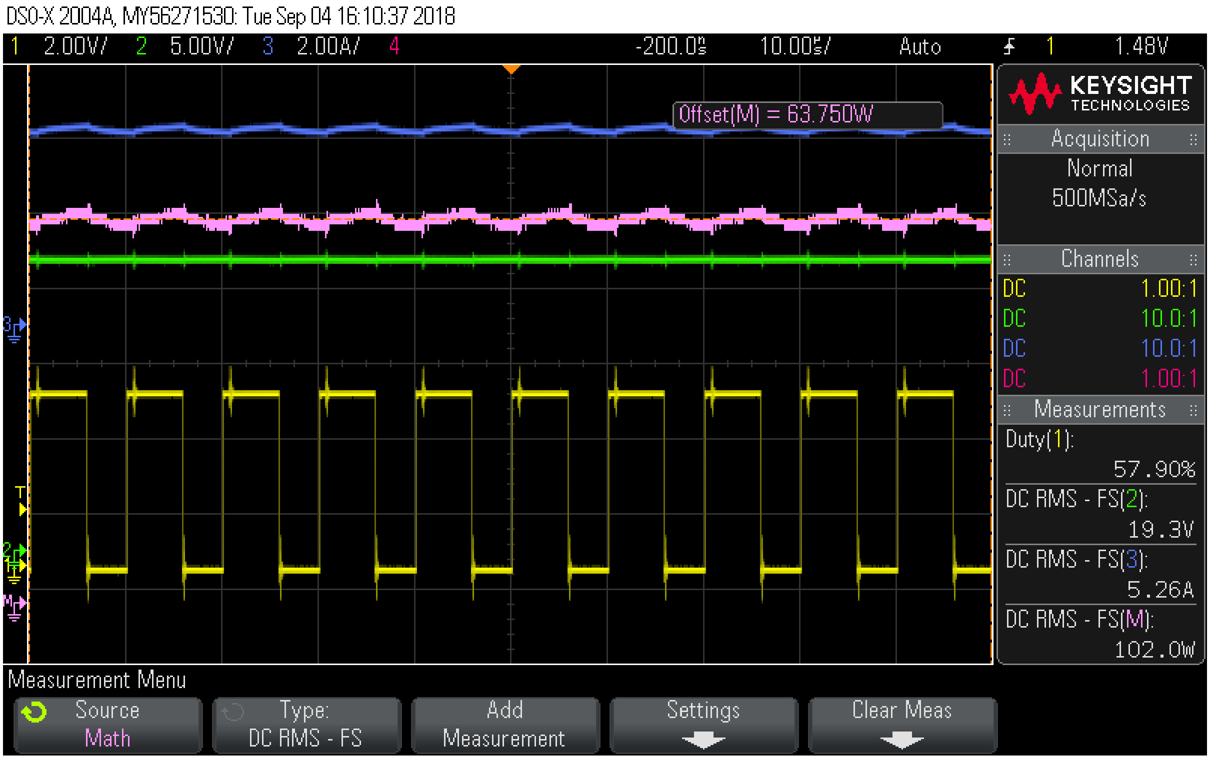


Figure 12: Readings at 0.55 A current limit

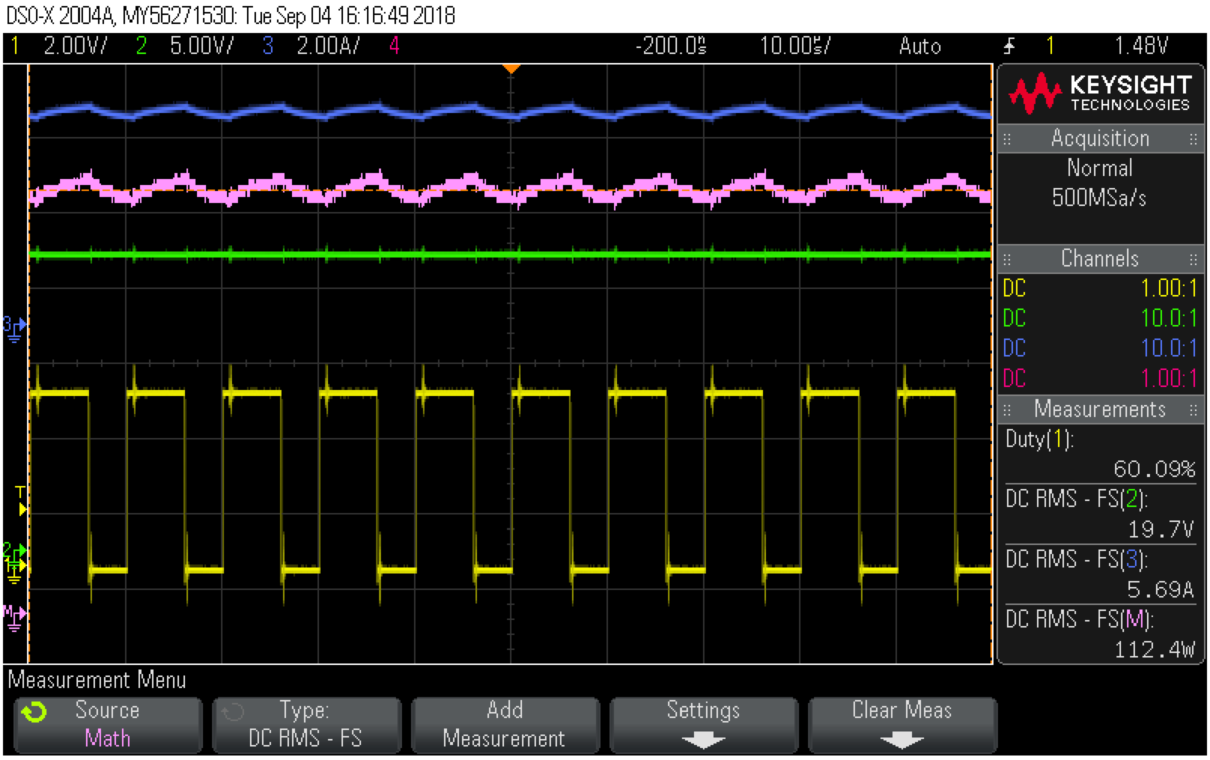


Figure 13: Readings at 0.6 A current limit

In all the screenshots above, the key for the colours is as follows:

Yellow – Duty Cycle
Green – Input Voltage
Blue – Input Current
Purple – Input Power (via MATH function on DSO)

It should be noted that the DSO settings for channel 3 (current) was set to a ratio of 10:1, which is incorrect as it should have been at 1:1. This has resulted in our current and power readings being off by a factor of 10. So keep in mind when looking at these figures that the results are correct, but current and power values must be divided by 10 in order to accurately represent their real values.

As you can see the code worked quite effectively at maintaining the MPP, as it was able to successfully adjust the duty cycle in order to maintain an input voltage at roughly the 19 V mark (which is the voltage required for the MPP of the PV cell which we received from our testing earlier on in the lab). There is a small amount of error which we believe could be reduced by fine tuning the code.

5.8 Analysis

i) Explain, with aid of equations and diagram, how the buck converter serves as a variable resistor to the PV panel.

To see how the buck converter function as a variable resistor to the PV panel without the use of diagram, first we need to extract its function in circuit through equations with the aid of the circuit shown below:

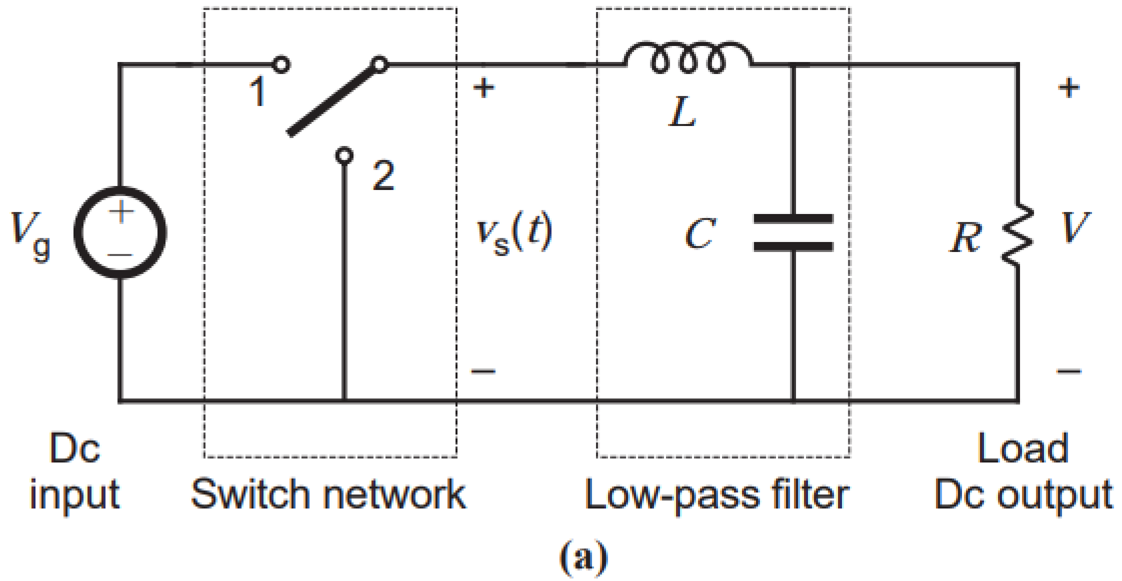


Figure 14: Simple buck converter system with switch network function as buck converter

The switching network consist of the mosfet working as the buck converter with the duty cycle (D).

$V_s(t) = D * V_g(t)$ (7)

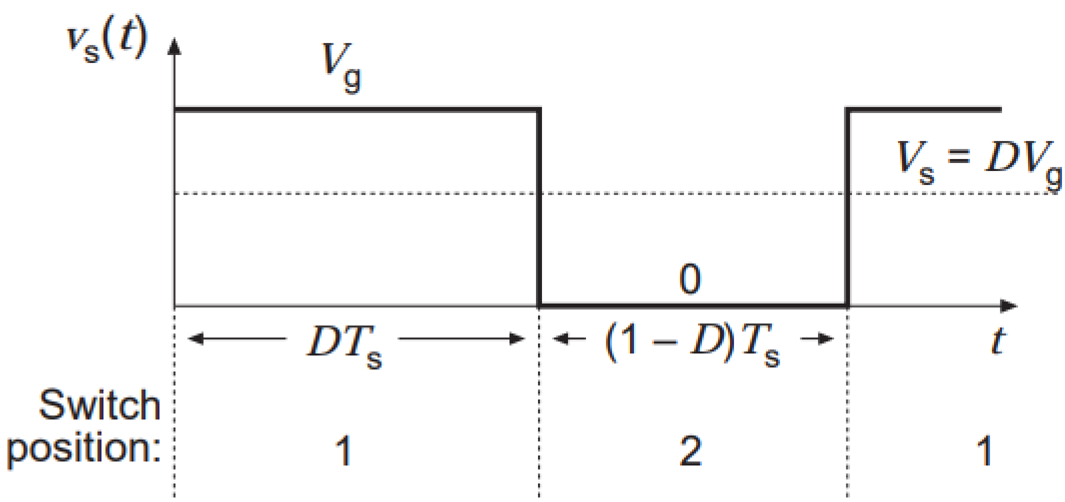


Figure 15: The relationship between duty cycle, input voltage and output voltage

D: duty cycle of buck converter.

$V_g(t)$: voltage sources.

Without the Low-pass filter, we can see that

$$I_{out} = \frac{V_s(t)}{R} = \frac{D*V_g(t)}{R} (8)$$

$$\frac{D}{R} = \frac{V_g(t)}{I_{out}} (9)$$

$$P = {I_{out}}^2 * (\frac{D}{R}) (10)$$

From the equation (8), we can see that the current I_{out} will change linearly to the duty cycle of the buck converter with the constant of resistor which prove that buck converter function as the variable resistor to PV system. Thus, we can conclude that the higher the duty cycle is, the higher the output current, power can increase.

To prove that the conclusion is corrected, we will use the aid from diagram to prove that when increasing the duty cycle, the power output also rise.

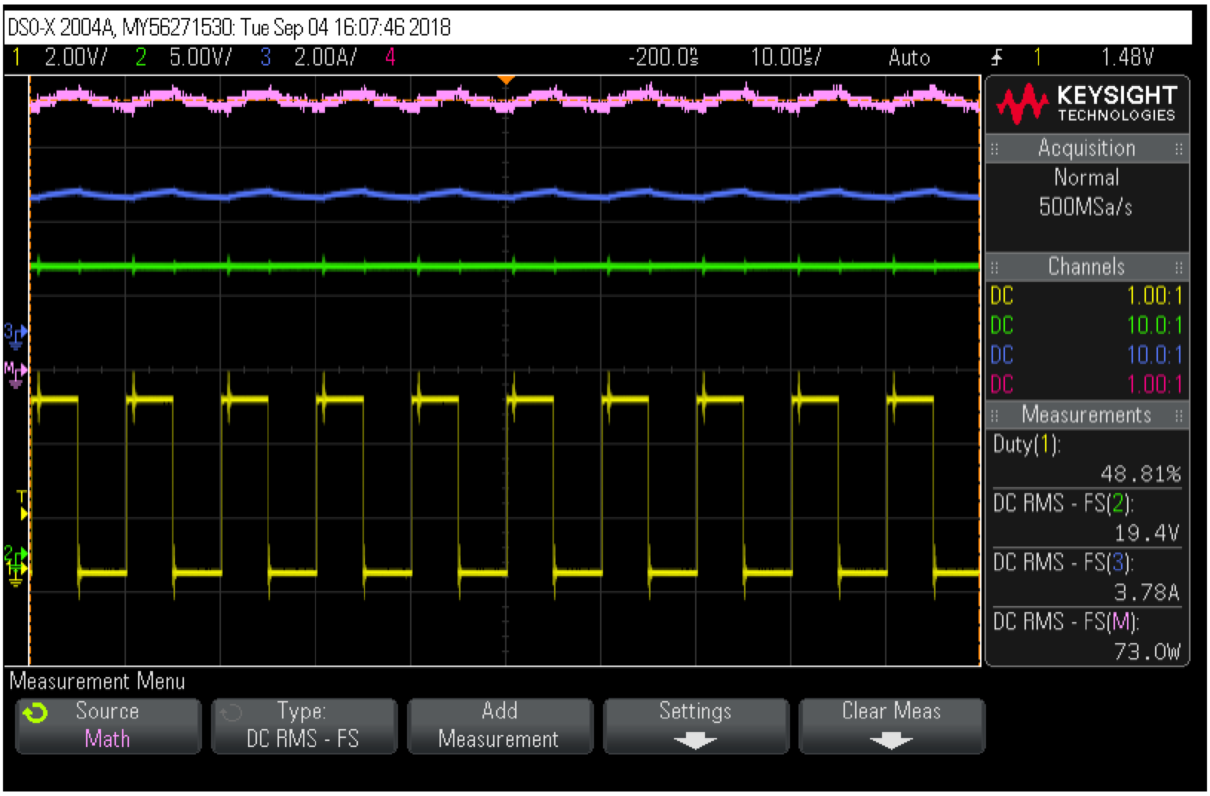


Figure 16: the maximum power with the duty cycle 48.81

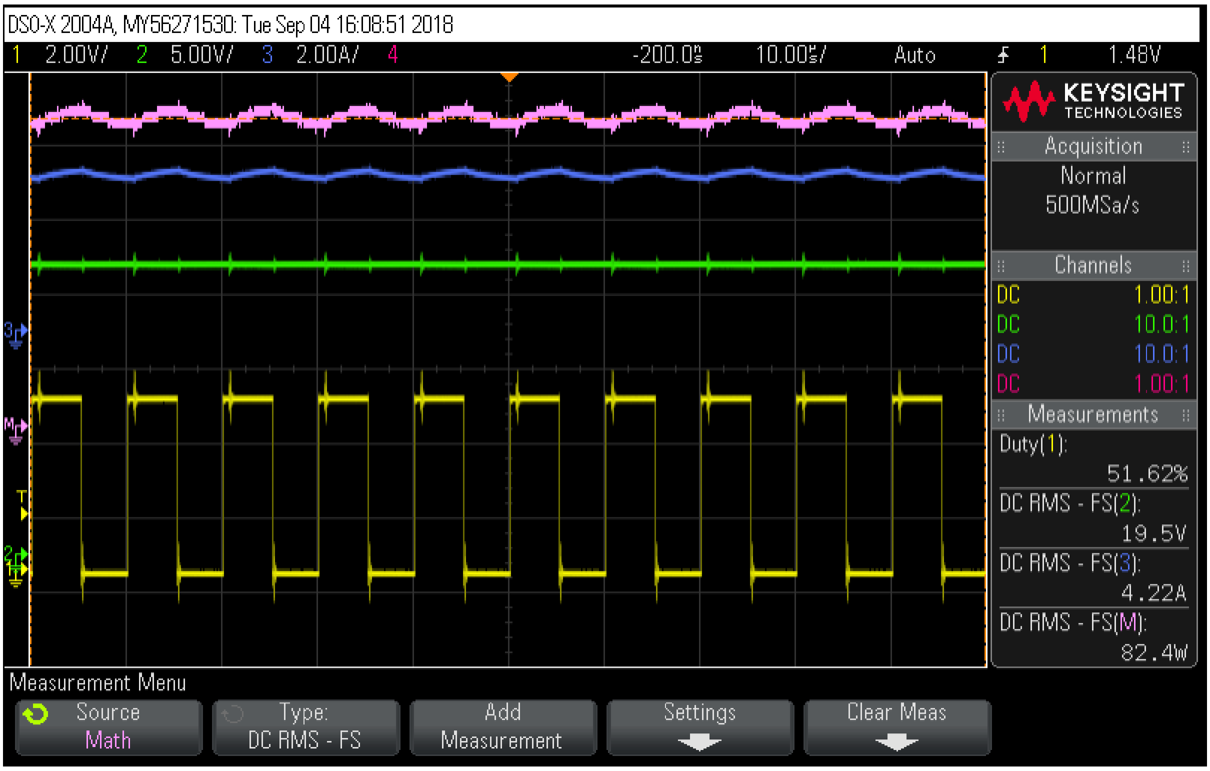


Figure 17: the maximum power with the duty cycle 51.62

From the figure 6, using the equation (9) with the duty cycle D = 48.81 (%), V =19.4 (V), I = 3.78 (A), we have

$$R = 9.51\ (\Omega)$$

which is close to 10(Ω).

Reference:

[1]D. Chariag and L. Sbita, "Design and simulation of photovoltaic emulator", *2017 International Conference on Green Energy Conversion Systems (GECS)*, 2017.

[2]R. W. Erickson, *DC-DC Power Converters*. Wiley Encyclopedia of Electrical and Electronics Engineering, 2018, p. 1.

ii) Explain your part of the code to achieve constant voltage reference MPPT with the support of experimental results

A. For the reader's reference, the code is displayed on the last page. To achieve constant voltage reference MPPT, the flow chart from earlier was used as a basis to form the code. In order to calculate the reference voltage, an average of our three MPPT values from the lab experimentation yielded a result of 18.7 volts. This was then used as our V_{PV} value in which case, a voltage divider was used to achieve a value of less than 5V (less than the operating voltage of the microcontroller). Using the 10-bit ADC (Analog-Digital converter) built into the PICAXE, a ratiometric value of 689 was achieved. The next page also displays the equations that we used to determine this value.

Assuming V_{pv} = 18.7 volts,

From Figure 1 – voltage divider

$$18.7\ \times \frac{1.8\ \text{k}\Omega}{1.8k\Omega + 8.2\text{k}\Omega} = 3.366$$

Using a 10-bit value of 1024 (2^{10}) and the expression below

$$\frac{\text{10 Bit Value}}{\text{System Voltage}} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}}$$

$$\frac{1024}{5} = \frac{x}{3.366}$$

$$x \cong 689$$

After obtaining this value, an *if* statement was used to compare the PV voltage against this reference value. If the PV voltage was greater than 689, then increase duty cycle, if not, then decrease duty cycle. This code would then ensure that PV voltage was be equal to reference voltage. From the experiment, as we increased the current limit for the input, the duty cycle would also increase. We can see from the scope graphs that the PV voltage was kept relatively constant ranging from 19.4-19.7 volts and that only the current increased. This can be compared to our excel results which show some similarity as the current limit is increased. Therefore, our experimental results and code are consistent with the theory behind Constant Voltage reference.

iii) Compare the constant voltage reference MPPT performance in section 5.7 against the identified true MPP's in section 5.1.

Below is a table comparing the measured values for both experiments in section 5.1 and 5.7 at a current limit of 0.4 A.

	True MPP (Section 5.1)	**Constant Voltage Reference MPP (Section 5.7)**
Current (A)	0.39	0.378
Voltage (V)	18.36	19.4
Power (W)	7.1604	7.3

As these readings are the only ones that can be directly compared due to sharing the same current value, we will compare them first and then look at the trends between the other results.

The results table above is evidence that our code served its purpose of maintaining the true MPP which we discovered during the PV testing stage. All constant voltage reference values are roughly within at least a 5% margin of the true values.

We can also see a pattern between the rising current limits and corresponding power readings between the results of both sections.

Current Limit (A)	**Current (A)**	**Voltage (V)**	**Power (W)**
0.2 (section 5.1)	0.18	18.68	3.3624
0.3 (section 5.1)	0.28	19.05	5.334
0.4 (section 5.1)	0.39	18.36	7
0.5 (section 5.7)	0.47	19.6	9.24
0.6 (section 5.7)	0.569	19.7	11.24

We can see from the results that the voltage is constantly hovering around the 19 V mark to ensure the MPP is maintained. Due to the relationship between current and voltage, with each rise in current by 0.1 A, we see a rise in power of roughly 2 W.

These results show that our experimental data is correct. Taking into consideration some minor errors that may have occurred during the lab we have still maintained accurate values and were successful in achieving maximum power point tracking.

5.6 - Programming Constant Voltage Reference MPPT

```
setfreq M32 'clock freq'
init:
symbol duty = w1                                   'w1 and w2 word variable'
symbol Vpv_temp = w2
duty = 159
pwmout C.2, 79, duty

main:
readadc10 C.4, Vpv_temp
pause 500

'*** Our Code ***
if w2 > 689 Then
                                                   'Increase the Duty Cycle'
        w1 = w1 +1
        pwmout C.2, 79, w1
        readadc10 C.1, Vpv_temp

elseif w2 < 689 Then                               'Decrease the Duty Cycle'

        w1 = w1 -1
        pwmout C.2, 79, w1
        readadc10 C.1, Vpv_temp

endif
'*** End our our code***

if duty > 271 then
        duty = 271
endif

if duty <79 then
        duty =79
endif
pwmout C.2, 79, duty
pause 1000
goto main
```