EXPERIMENT 3-1 LAB REPORT

ECEN 5517 (Spring 2017)
Power electronics and Photovoltaic Power Systems Laboratory

2/20/2017

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Objectives

The objectives of this experiment are:

- To design an 85W dc-dc Buck converter power stage to charge a 12V battery from solar panel
- To test the buck converter under open loop conditions

Experimental data

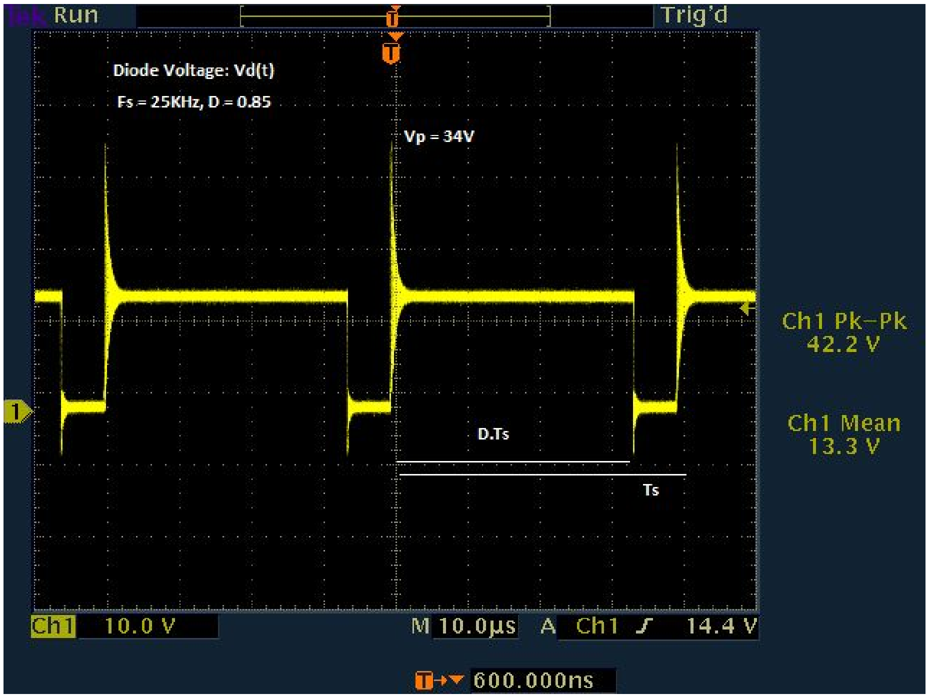
Equipments used

Power	Measurement
Power Supply: 30V-5A Dual Power Supply Rheostat: 0 -15.5 Ohms	Meter1: FLUKE 45 Oscilloscope: LCR Meter

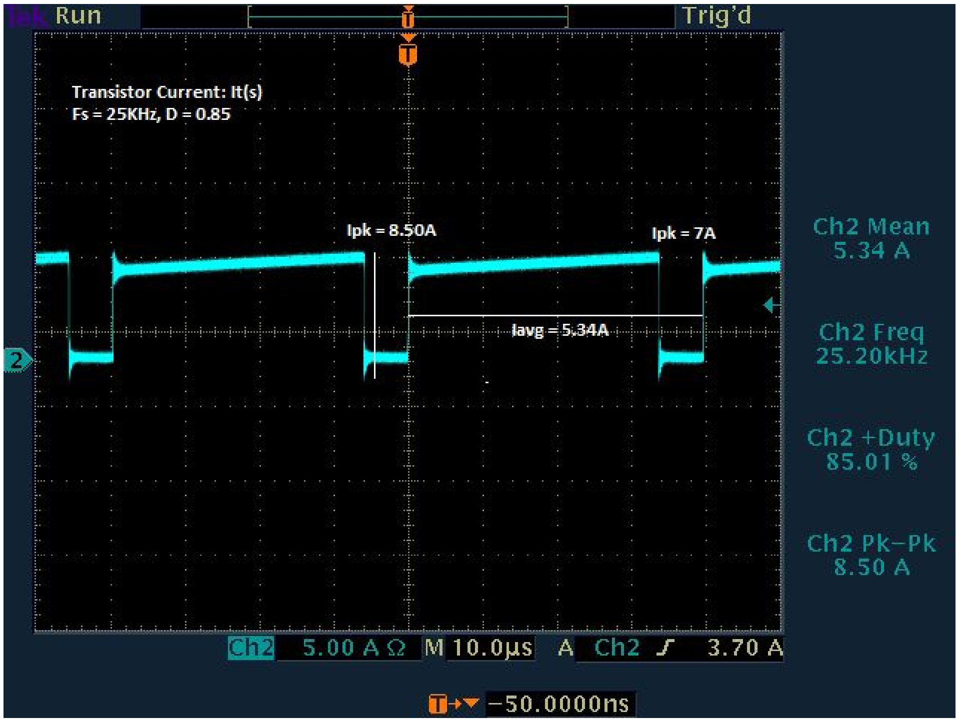
Buck Converter Load Test Waveforms

Test Conditions:
Open loop, ~85W load
Output: 13V, 6.5A; Input: 16V

1. Diode voltage $v_D(t)$

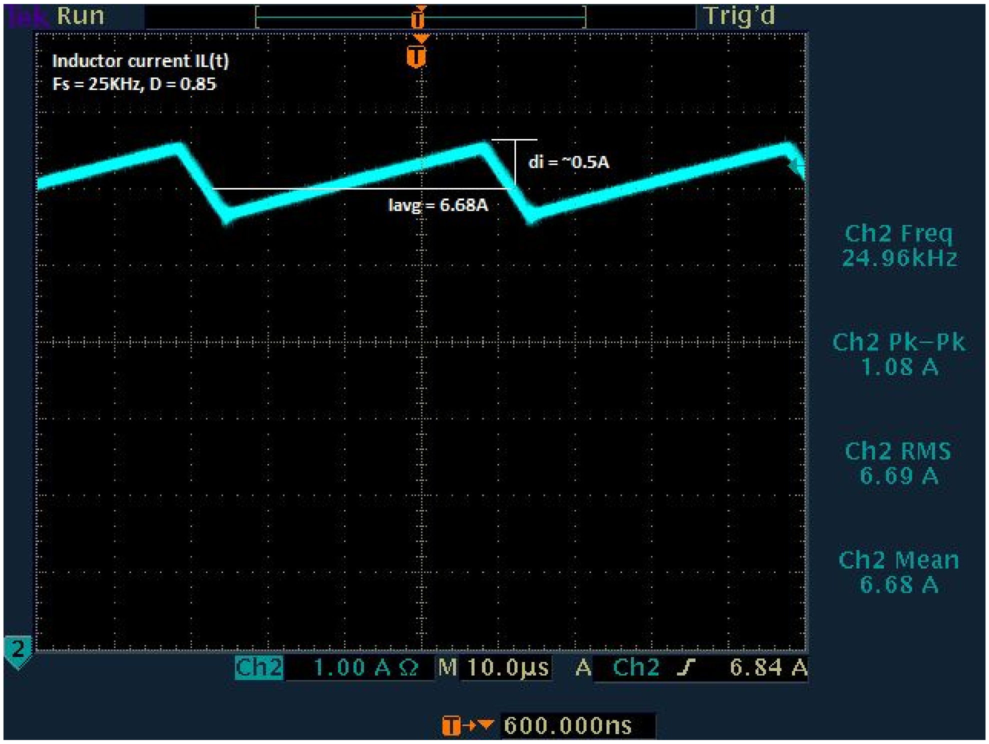


2. Transistor Current $i_T(t)$

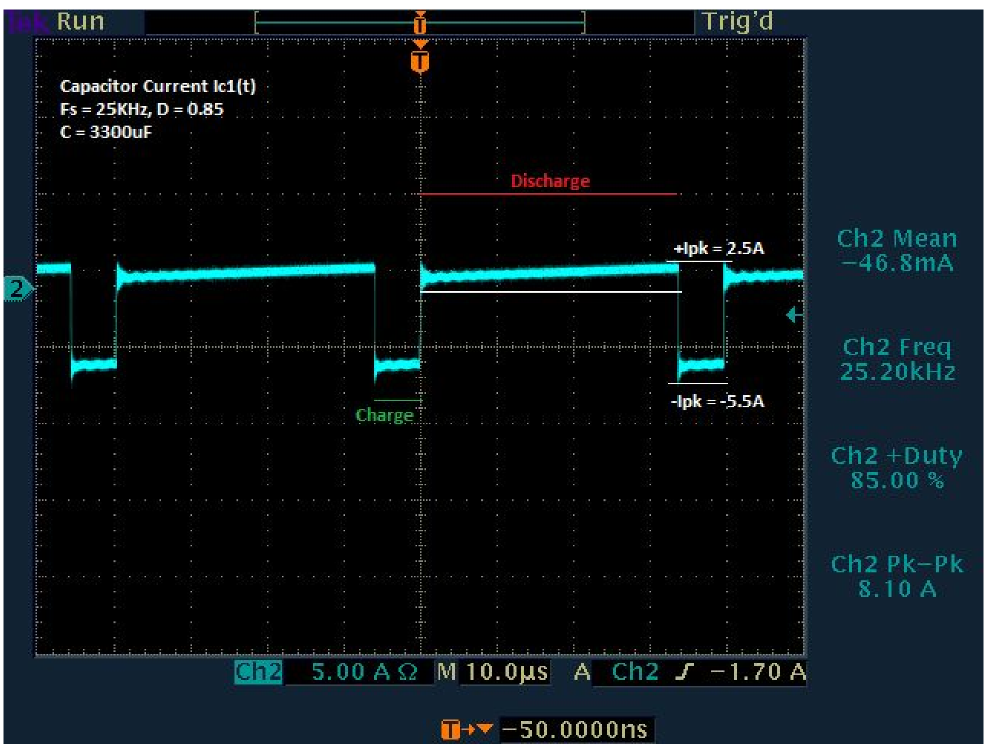


3. Diode Current $i_D(t)$

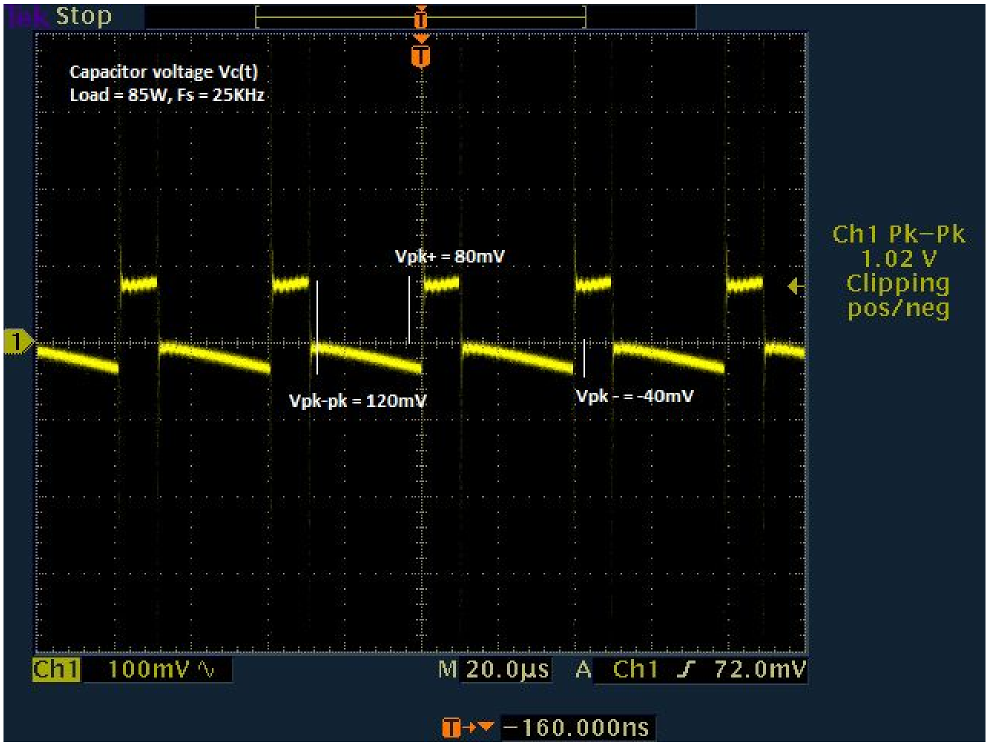
4. Inductor Current $i_L(t)$



5. Capacitor Current $i_{C1}(t)$



6. Capacitor Voltage $v_{C1}(t)$



Inductor Current Ripple

Ripple as per inductor design (Theoretical)

Inductance (uH)	D	Fs (kHz)	Iripple(A) (Ipk - Iavg)
80.9	0.85	25	0.482

Ripple Observed (Measured)

D	Fs (kHz)	Ripple(A) (Ipk - Iavg)
0.85	25	0.54

- The actual inductance measured with LCR meter was approximately 90uH
- The ripple measured matches theoretical value within acceptable measurement errors

Input Capacitor ESR measurement

From capacitor voltage and current waveforms we can calculate the R_{esr} as follows:

$$\mathbf{R_{esr} = V_{pk}/(I_{pk\_charging})}$$

$= 80mV/5.5A$

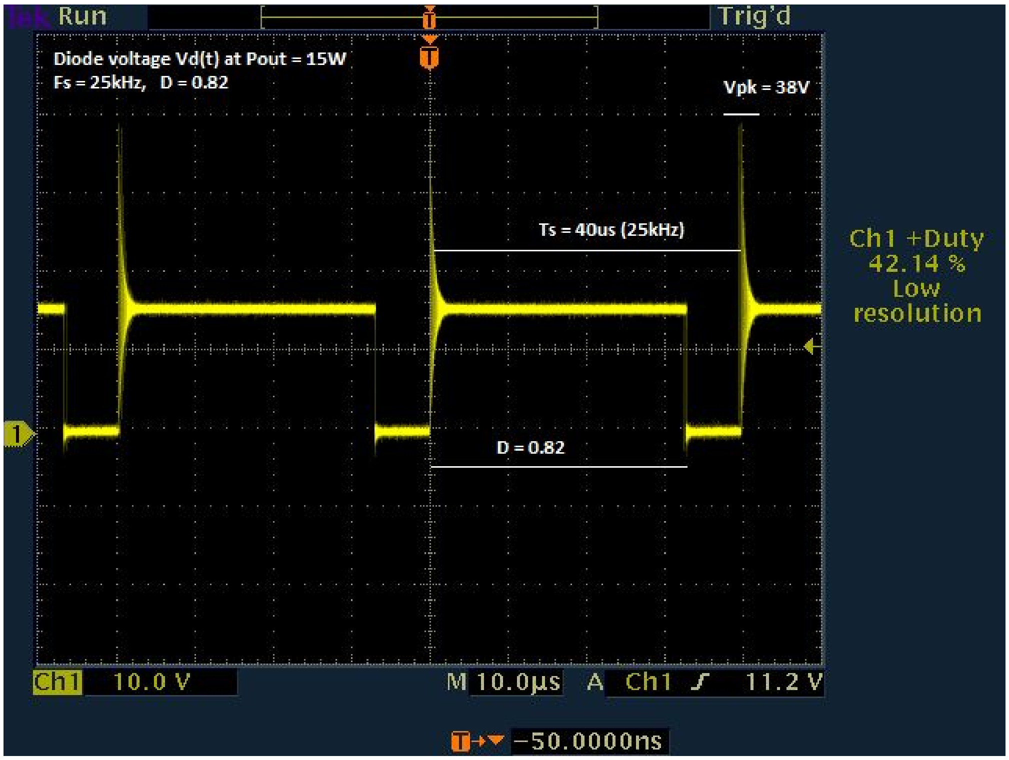
$= 0.0145$ Ohms

- This matches the R_{ESR} specified in the datasheet which is 0.014 Ohms
- Thus the power P_C through the capacitor is $I_{RMS}^2 * R_{ESR} = 2.5^2*0.145 = 0.90625W$.
- This datasheet RMS rating of the current is 4.22A. We are well within the spec

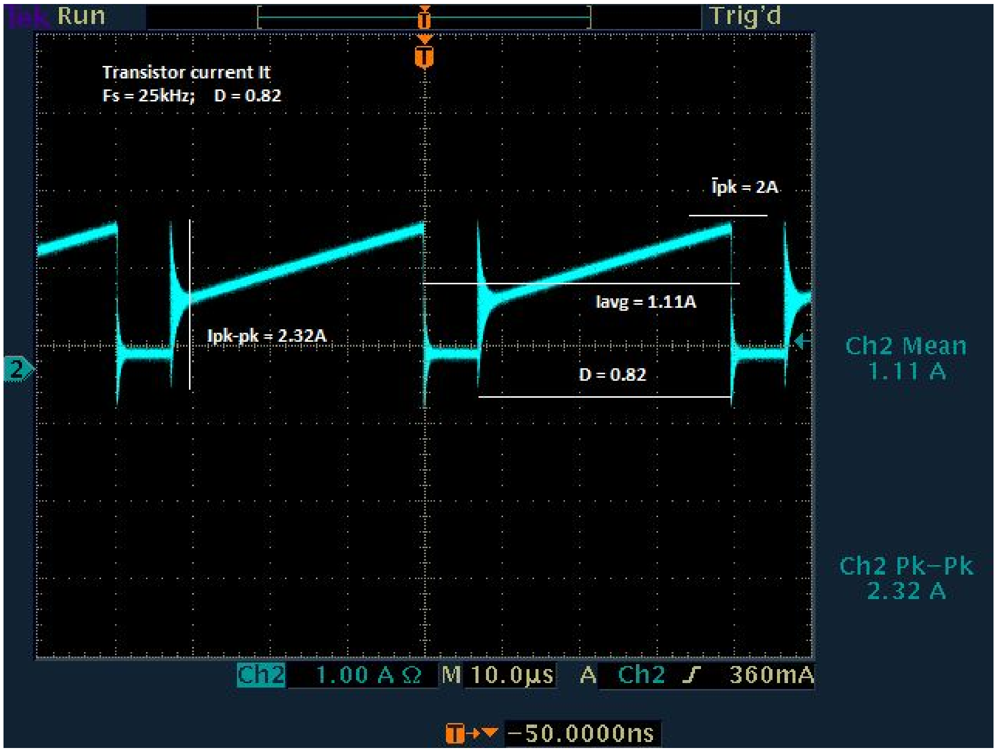
Load Test

1. Pout = 15W

Diode voltage $v_D(t)$

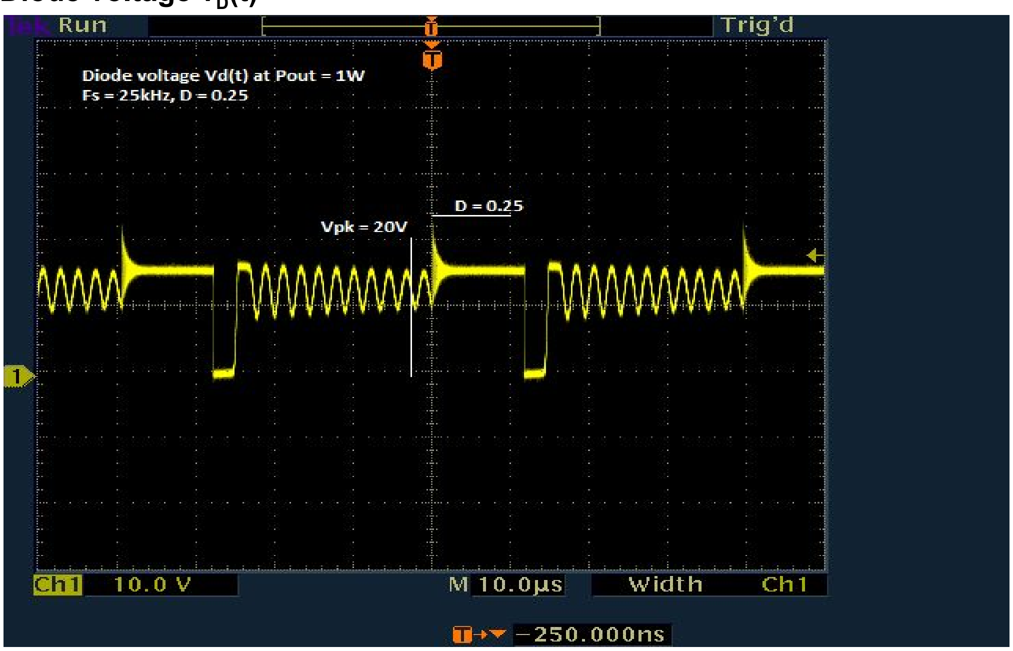


Transistor current $i_T(t)$

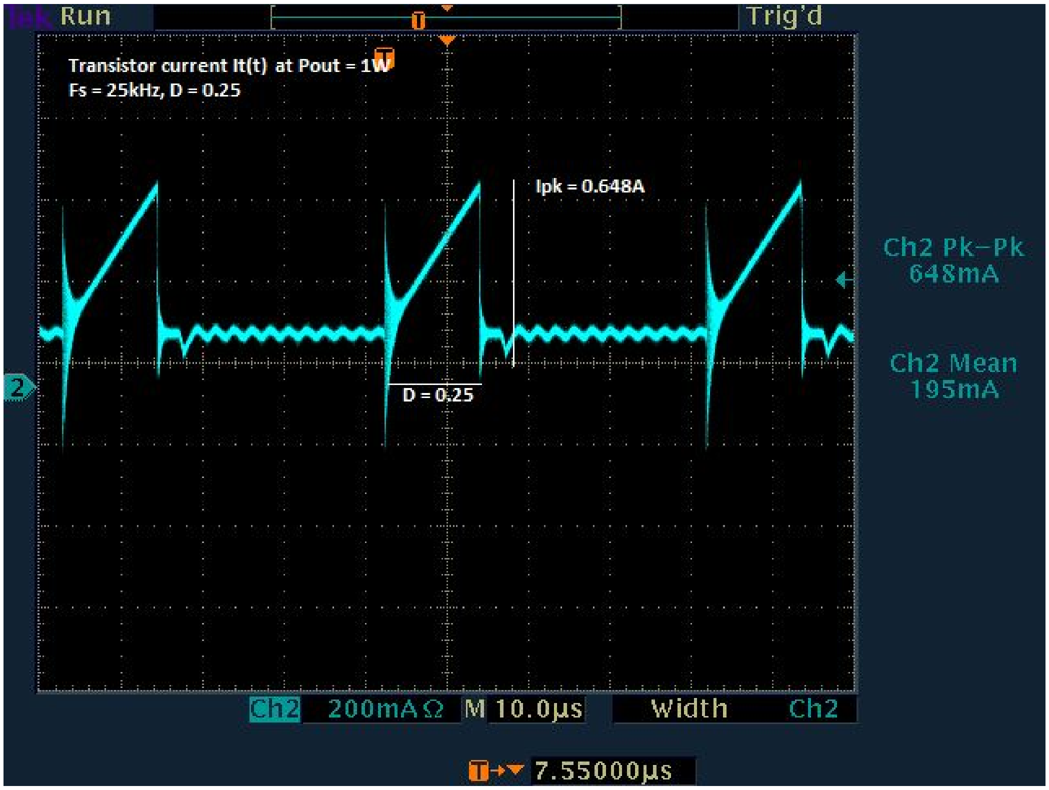


2. Pout = 1W

Diode voltage $v_D(t)$



Transistor current $i_T(t)$



Duty Cycle measurement at different power levels

Vin (V)	Vout (V)	Iout (A)	Power (W)	Duty
16	13.09	6.68	87.5	0.85
16	13.07	1.15	15	0.82
16	13.1	0.065	1	0.25

- From the above table it can be seen that, the change in duty cycle to regulate 13.0V is not drastically different (around 85%) between 85 to 15W
- It does change quite a bit (to 25%) when the output power is reduced to 1W
- This is because the system is in Continuous conduction mode (CCM) for both 85 and 15W. Therefore the duty cycle is almost independent of load. It does fall to 0.82 at 15W because the conduction losses reduce
- When Pout = 1W, the system goes to discontinuous conduction mode (DCM). In this case, lower duty cycle is required to maintain the same output voltage

Open loop PV measurements

Duty	Vpv (V)	Ipv (A)	Ppv (W)	Vbat (V)	Ibat (A)	Pbat (W)
0.1	20.57	0.018	0.37026	12.26	0	0
0.15	20.52	0.044	0.90288	12.26	0.038	0.46588
0.2	20.49	0.068	1.39332	12.26	0.066	0.80916
0.25	20.43	0.112	2.28816	12.26	0.12	1.4712
0.3	20.37	0.159	3.23883	12.27	0.176	2.15952
0.35	20.33	0.207	4.20831	12.27	0.233	2.85891
0.4	20.24	0.278	5.62672	12.27	0.315	3.86505
0.45	20.18	0.342	6.90156	12.28	0.39	4.7892
0.5	20.1	0.427	8.5827	12.28	0.489	6.00492
0.55	20.07	0.487	9.77409	12.29	0.558	6.85782
0.6	20.05	0.608	12.1904	12.29	0.699	8.59071
0.65	19.76	1.125	22.23	12.34	1.28	15.7952
0.7	19.07	2.264	43.17448	12.4	3.228	40.0272
0.71	18.87	2.421	45.68427	12.41	3.398	42.16918
0.72	18.69	2.58	48.2202	12.42	3.579	44.45118
0.73	18.52	2.747	50.87444	12.43	3.759	46.72437
0.74	18.34	2.871	52.65414	12.44	3.872	48.16768
0.75	18.15	2.98	54.087	12.45	3.97	49.4265
0.76	17.97	3.097	55.65309	12.45	4.07	50.6715
0.77	17.79	3.216	57.21264	12.46	4.175	52.0205
0.78	17.61	3.325	58.55325	12.46	4.259	53.06714
0.79	17.43	3.423	59.66289	12.47	4.329	53.98263
0.8	17.25	3.501	60.39225	12.47	4.38	54.6186
0.81	17.06	3.585	61.1601	12.48	4.432	55.31136
0.82	16.88	3.657	61.73016	12.48	4.455	55.5984
0.83	16.7	3.712	61.9904	12.48	4.478	55.88544
0.84	16.51	3.759	62.06109	12.48	4.475	55.848
0.85	16.33	3.79	61.8907	12.48	4.469	55.77312
0.86	16.14	3.837	61.92918	12.48	4.465	55.7232
0.87	15.97	3.87	61.8039	12.47	4.455	55.55385
0.88	15.78	3.88	61.2264	12.47	4.421	55.12987
0.89	15.6	3.909	60.9804	12.47	4.395	54.80565
0.9	15.42	3.91	60.2922	12.46	4.359	54.31314
0.91	15.25	3.93	59.9325	12.46	4.326	53.90196
0.92	15.07	3.941	59.39087	12.45	4.283	53.32335
0.93	14.9	3.94	58.706	12.45	4.24	52.788
0.94	14.74	3.945	58.1493	12.45	4.198	52.2651

0.95	14.57	3.945	57.47865	12.44	4.156	51.70064
0.96	14.41	3.94	56.7754	12.43	4.109	51.07487
0.97	14.25	3.94	56.145	12.43	4.063	50.50309
0.98	14.09	3.938	55.48642	12.43	4.026	50.04318
0.99	13.94	3.937	54.88178	12.43	3.976	49.42168

Open loop PV Plots

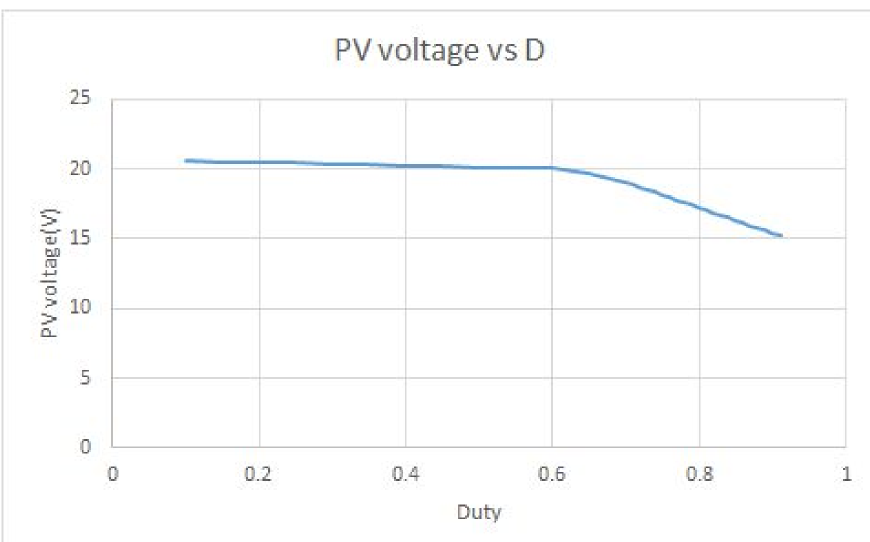
An approximate estimate of load current I_{CRIT}, below which converter operates in DCM

$\mathbf{R_e}$ = 2*L*Fs/D^2
= 2*80u*25e3/$(0.6)^2$; where D = 12/20
= 11.11 Ohms

$\mathbf{I_{CRIT}}$ = Vg*(1-D)/(D*Re)
= 20*0.4/(0.6*11.11)
= 1.20A

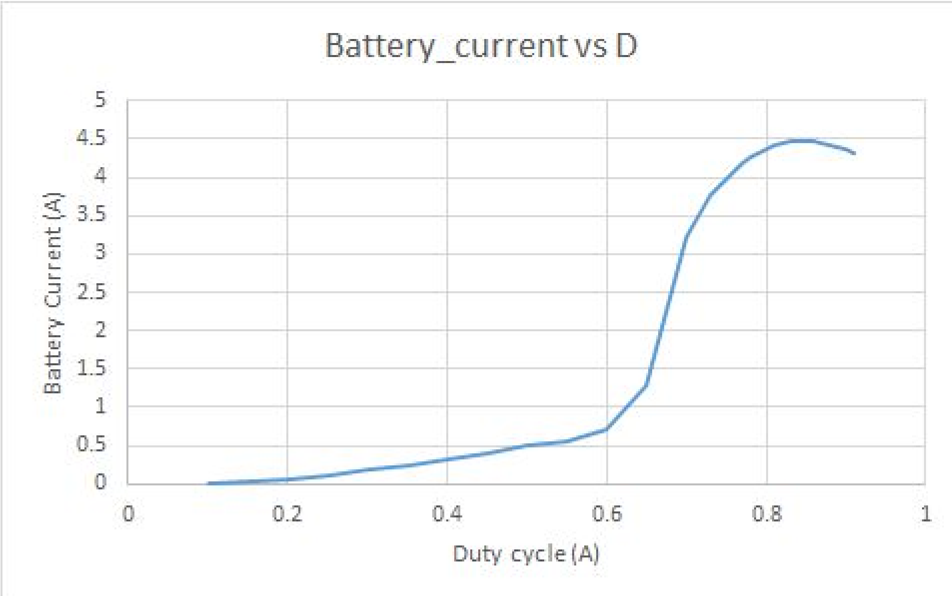
Thus for currents below 1.20A and duty cycles below 0.6 converter will operate in DCM

1. PV Voltage vs D



EXPLANATION
For duty cycles below **0.6** the current drawn from the panel is very low. Thus the converter operates in **DCM** and the change in PV voltage is negligible (**from 20.5V to 20.05V**). Above 0.6 when the converter shifts to **CCM** the voltage starts to fall rapidly as the current drawn is increased. The MPP voltage of **16.7V** is reached around **D = 0.83**.

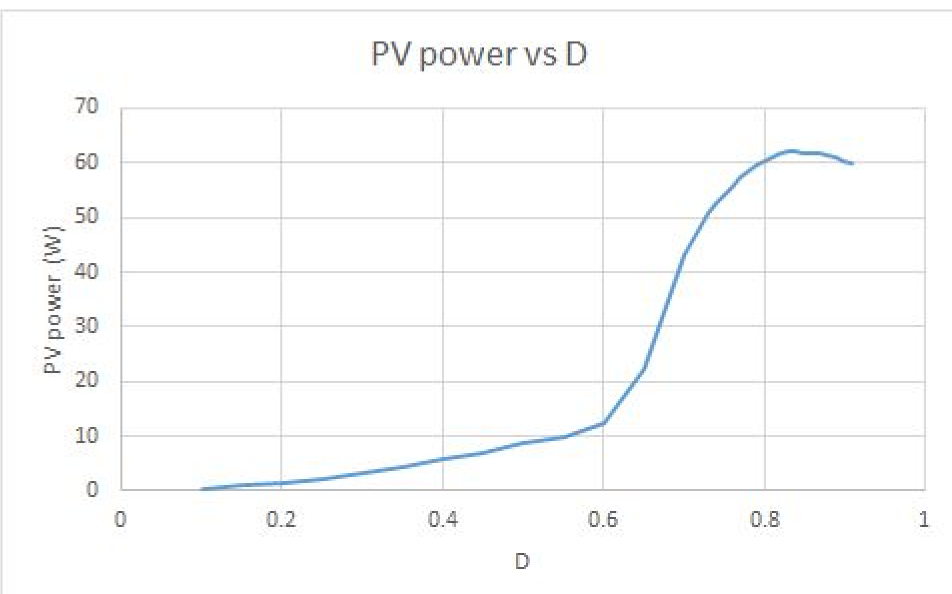
2. Battery current vs D



EXPLANATION

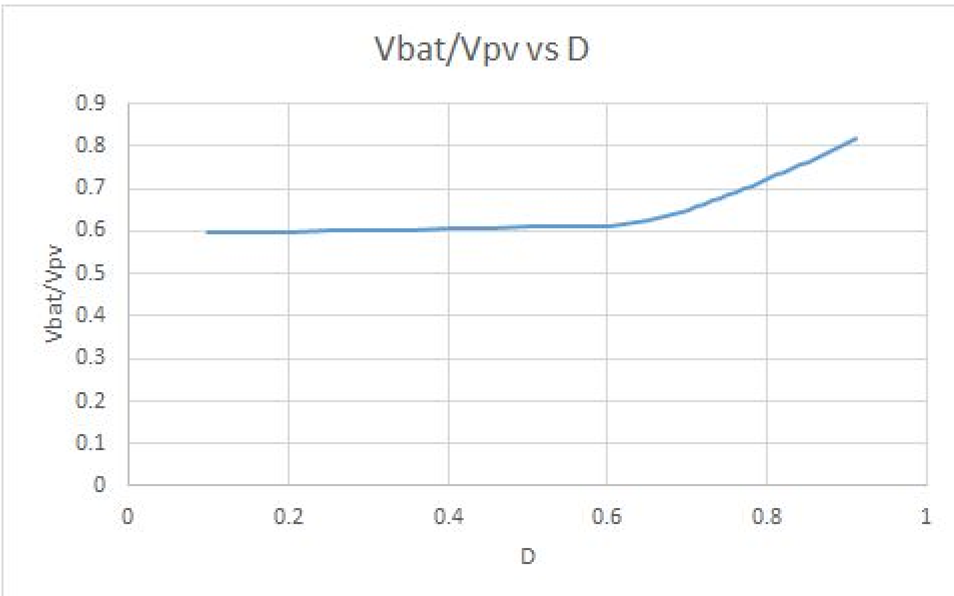
When the converter is **DCM** for **D < 0.6** the battery current drawn is very low. As duty cycle increases current rises above $\mathbf{I_{CRIT} > 1.28}$, the converter moves to CCM and current starts to rise rapidly. The MPP is reached at $\mathbf{I_{BAT} = 4.478A}$ around **D=0.83**. Beyond this duty cycle the current starts to fall as Input power available reduces.

3. PV power vs D



EXPLANATION
At low duty cycles, when converter operates in DCM the power increases with a small slope. At **D>0.6** when the converter operates in CCM battery current current begins to rise rapidly. Hence the power rises rapidly. MPP point is reached around **62.8W** at **D = 0.8**. Beyond this point the panel voltage falls rapidly and panel current remains more or less constant. This causes the power to decrease.

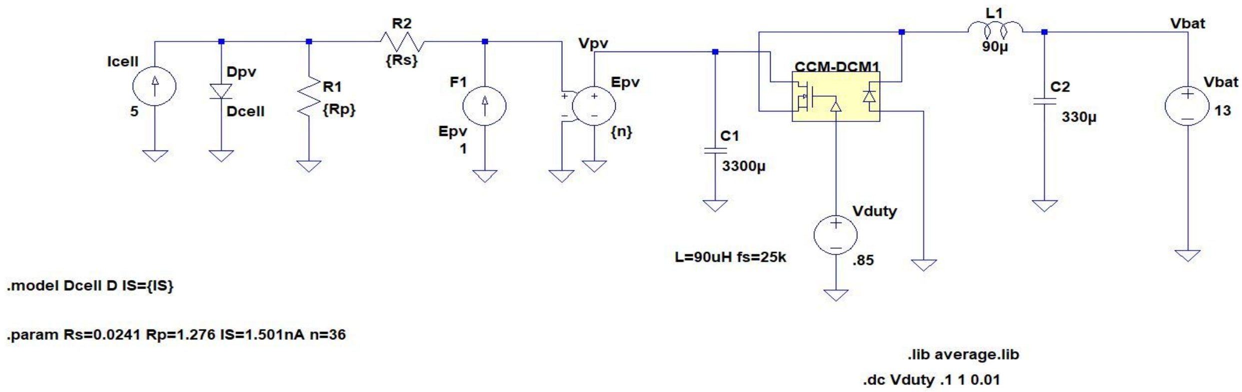
4. Vbatt/Vpv vs D



EXPLANATION
The battery voltage remains more or less constant throughout the entire range of duty cycle. The variation in the above curve is entirely due to panel voltage variations. In DCM when power drawn from the panel is much lower compared to MPP, the panel voltage decreases with a small slope. In this region, Vbat/Vpv remains more or less constant.
During CCM operation, panel voltage rapidly decreases and hence Vbat/Vpv increases with a much steeper slope.

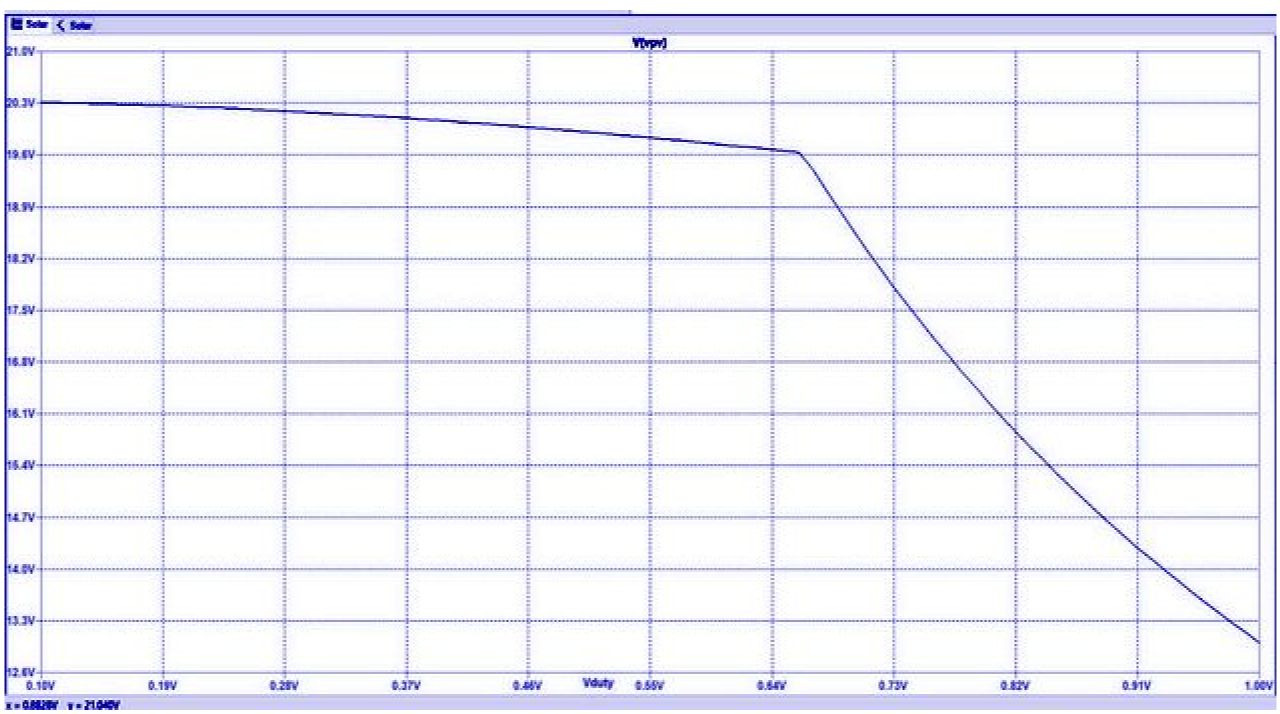
SPICE Simulation

SIMULATION MODEL

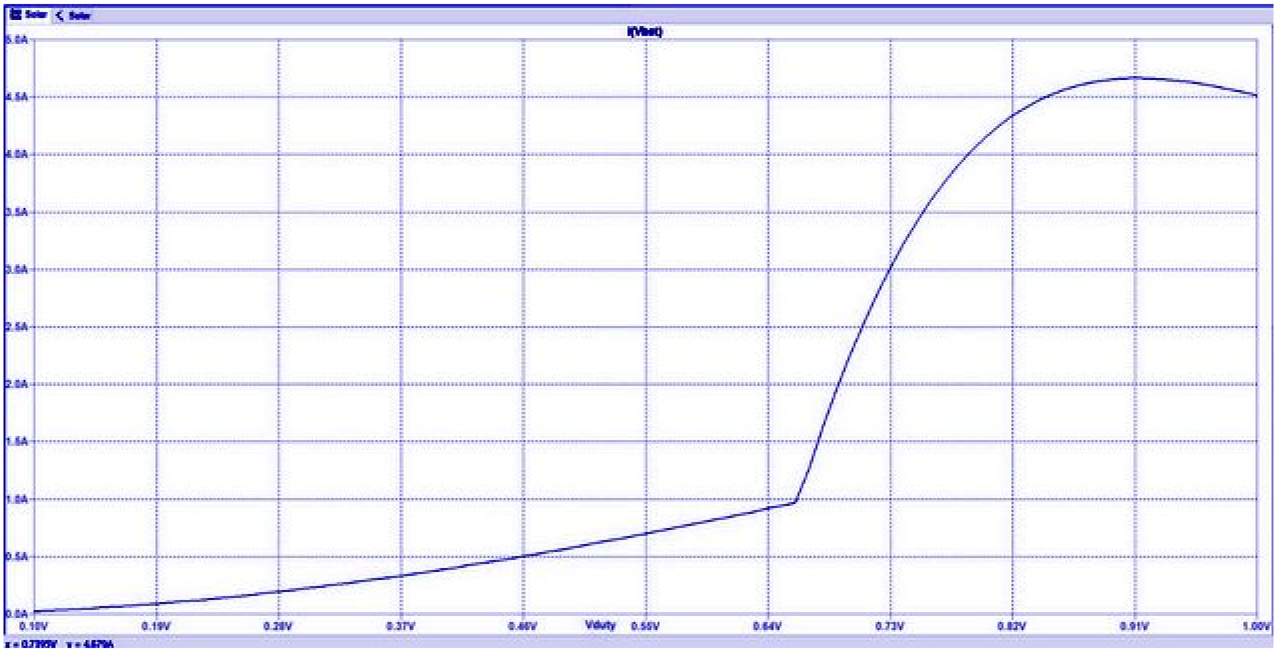


PLOTS

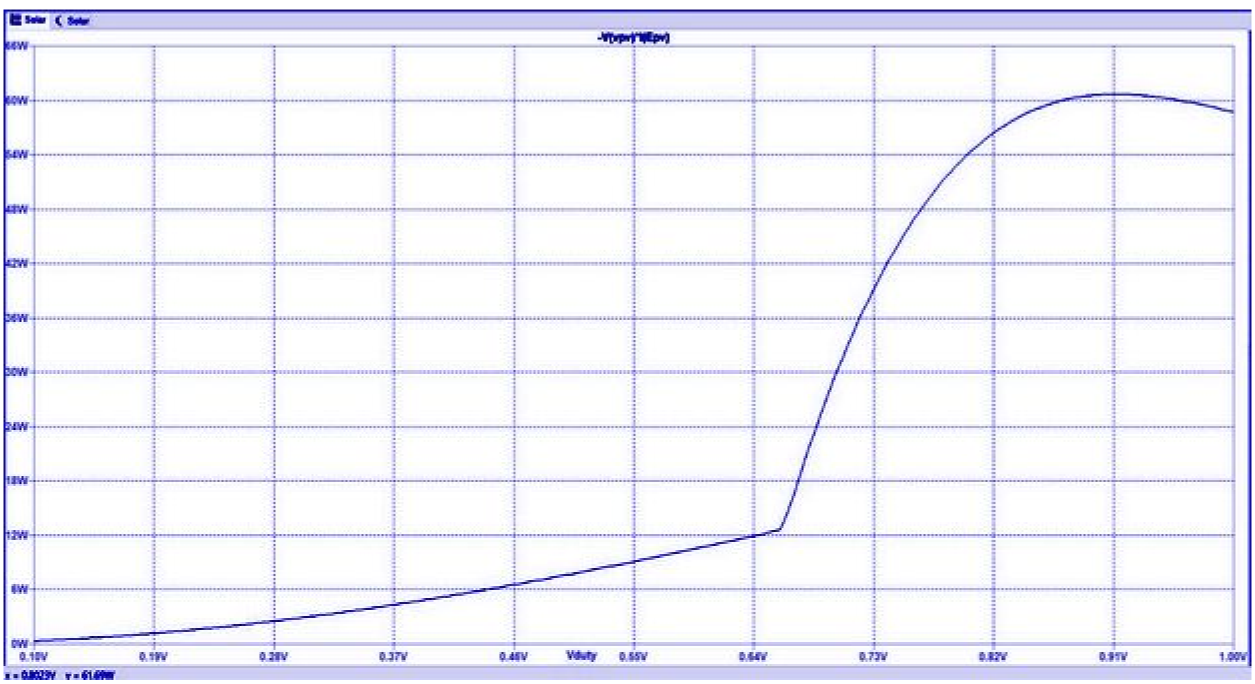
1. Panel voltage vs D



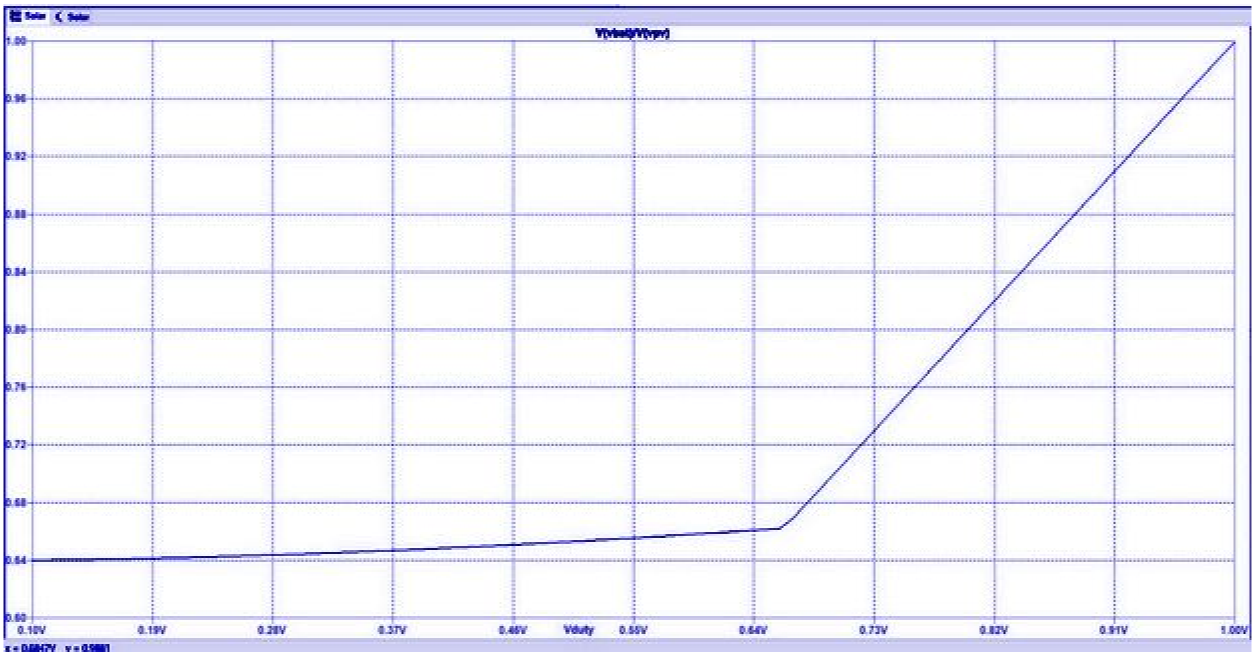
2. Battery Current vs D



3. PV power vs D



4. Vbat/Vpv vs D



- The simulation plots ignore the following effects:
    - The model does not take into affect the temperature variations on MPP voltage
    - The buck converter modelled is an ideal converter. It does not take into account the converter losses
    - Irradiation was not exactly measured to match the short circuit current of the model
- The model and the measured readings vary in the following aspects:
    - The theoretical MPP voltage (**14.5V)** is lower than measured value (**16.5)** since
    - The theoretical MPP duty cycle (**D = .91**) is higher than observed duty ratio (**D = 0.85**)
- As per measured readings operating at optimum duty cycle will yield an output power of almost 55.8W. Compared to this the direct energy transfer in Experiment 1 yielded only 26.6W. Note that the irradiation of both experiments were different. But we can still conclude that a Buck converter approach yields higher extraction power than DET approach.

Conclusion

- A buck converter was designed and tested in open loop conditions for a fixed load. An efficiency of 96% was observed with fixed load of 85W and 13V output.

- The converter was tested in open loop with solar panel and a 12V battery was charged. It was found that using a buck converter to charge a battery yielded in higher extraction from the panel than Direct Energy transfer approach