ECE1086

Homework 2 – Simulation of a Single-Phase Grid Tied Solar Micro-Inverter

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Part A: Converter Modelling

Using the PV, PV temperature, and MPPT algorithm from Assignment 1, a two-phase controller and single-phase full-bridge inverter were designed in order to simulate DC/AC conversion and support to a grid-tied environment. In addition to this, two control loops were also designed into order to perform pulse width modulation (PWM) for both the converter and inverter.

The converter takes in the current of the cell, has a capacitor, two magnetizing transformers, and two mosfets with PWM. The voltage of the capacitor is assumed to be Vpv, and thus it is controlled using both the MPPT system and the PWM of the two mosfets. The system operates at 10kHz.

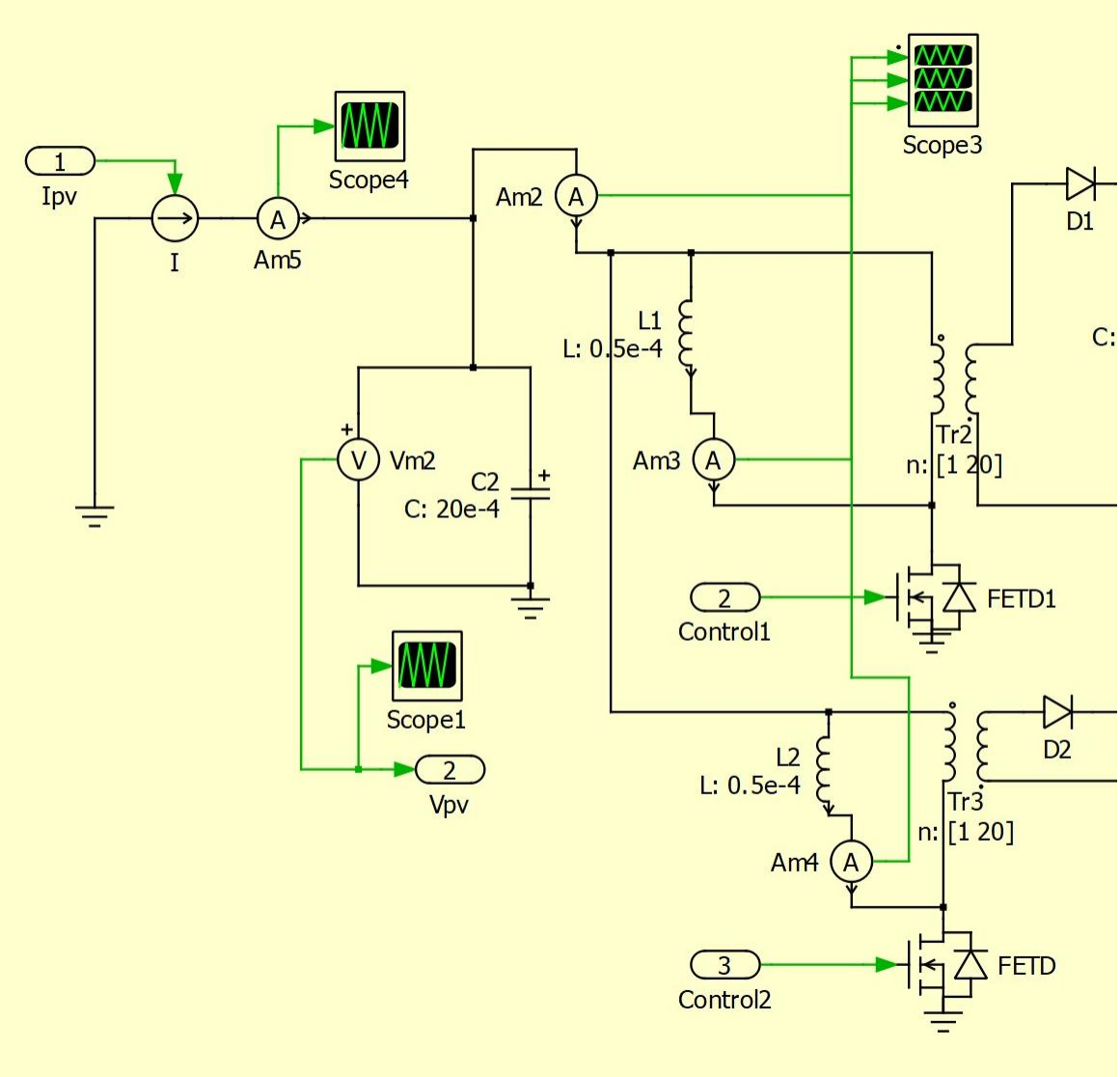

Figure 1: The design of the Converter in PLECS

Part B: Inverter Modeling

The inverter design uses a full bridge, single phase inverter. PWM is again used to control the grid current in order to match the AC grid voltage, specifically using Hysteretic Current-Mode Control. An LCL filter with a resistor dampener is used to filter the current to obtain a low-THD waveform.

The specifications of the LCL filter are:
L = 40 mH
C = 200 uF
R = 50 Ω

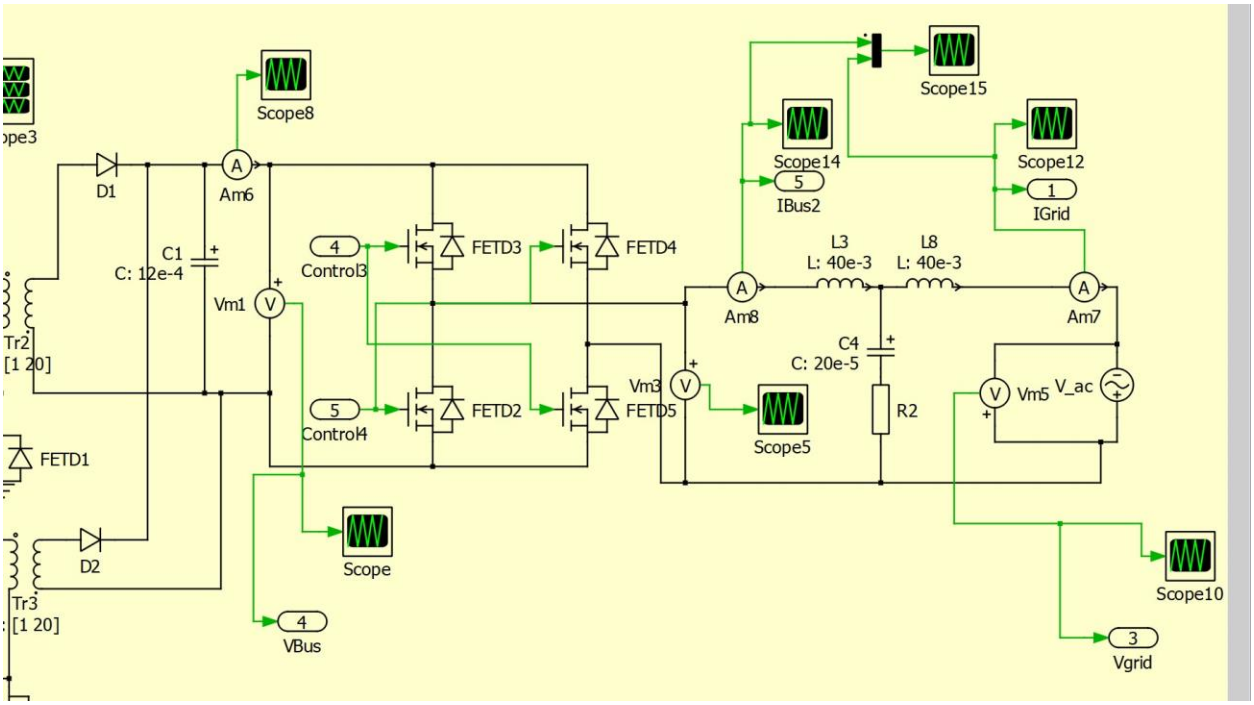

Figure 2: The design of the Inverter in PLECS

Part C: Control Systems

Two control systems are used. The first uses PWM to control the input voltage (Vpv) of the controller. The Second uses Hysteretic Current-Mode Control (HCMC) to again use PWM and control the grid current (Igrid) of the inverter.

The PI of the first control system uses a P gain of -2 and an I gain of -2.
The PI of the second control system uses a P gain of 1/10 and an I gain of 0.5.

I_{pk} for the HCMC was set to 1.25 * I_{ref}
I_{val} for the HCC was set to 0.75 * I_{ref}
V_{bus} was chosen to be held constant at 382V, a value above both the V_{pv} and V_{grid}.

Figures showing the detailed control systems in Simulink are shown on the next page

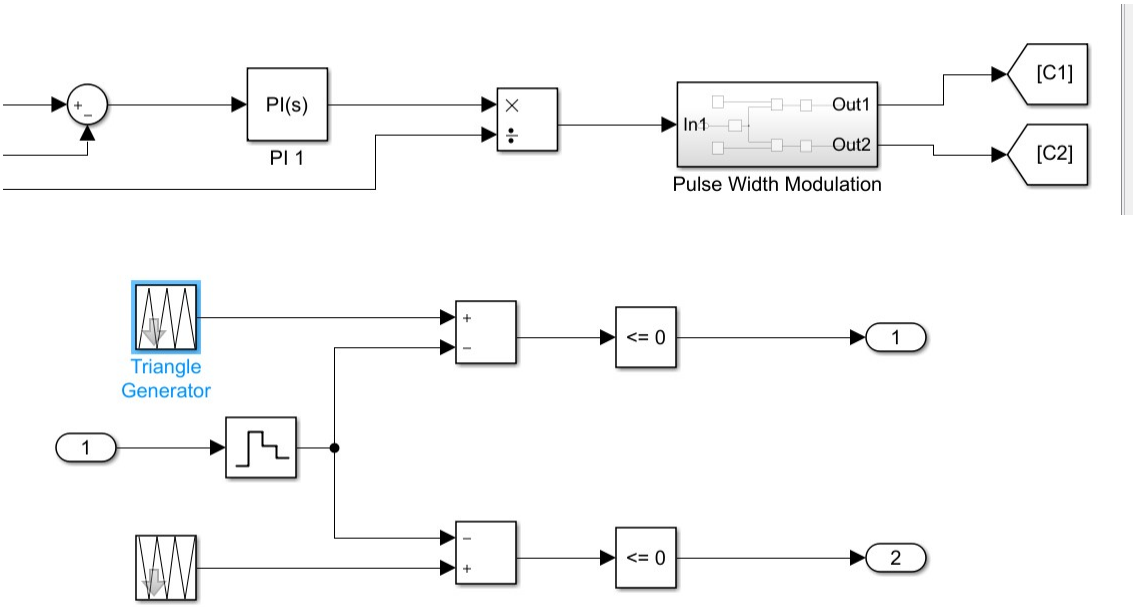

Figure 3: The overall, and PWM architecture for the Control of Voltage input (V_{pv})

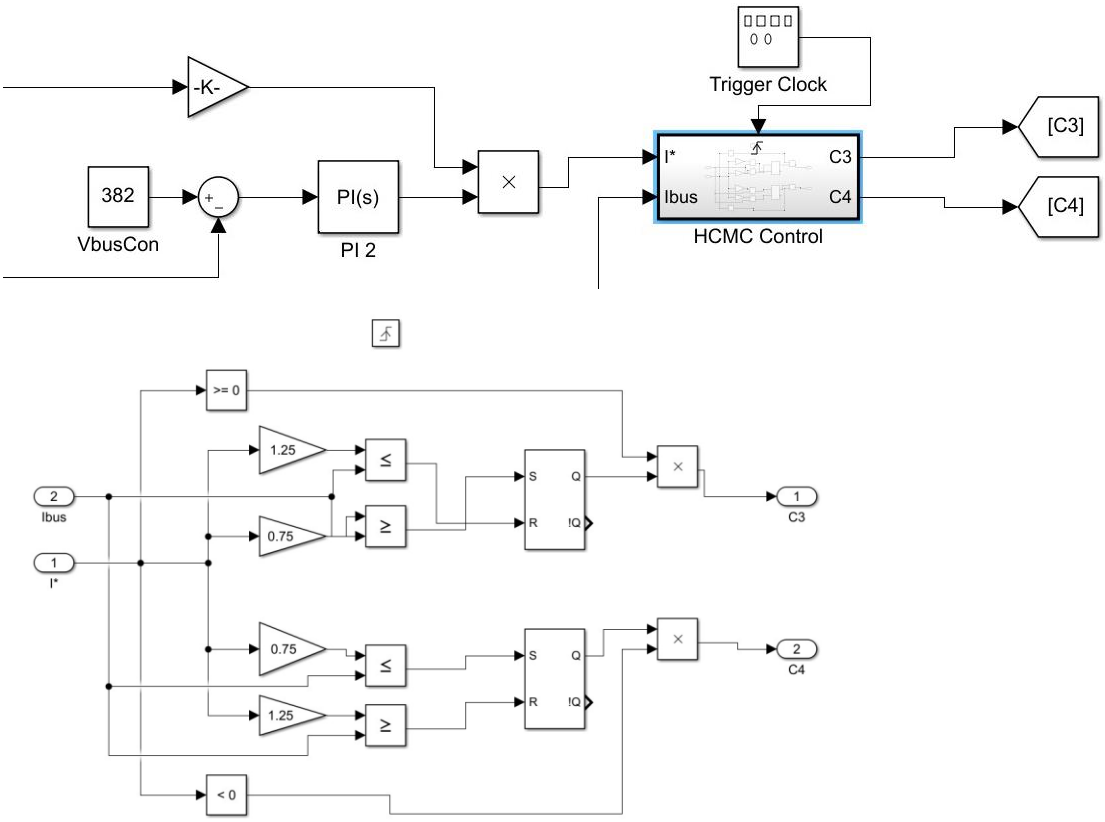

Figure 4: The overall, and HCMC architecture for the Control of Grid Current (I_{grid})

Part D: Steady State Performance

Performance at 1000 W/m^2:

THD: 1.5%
N_{MPPT}: 87.7%

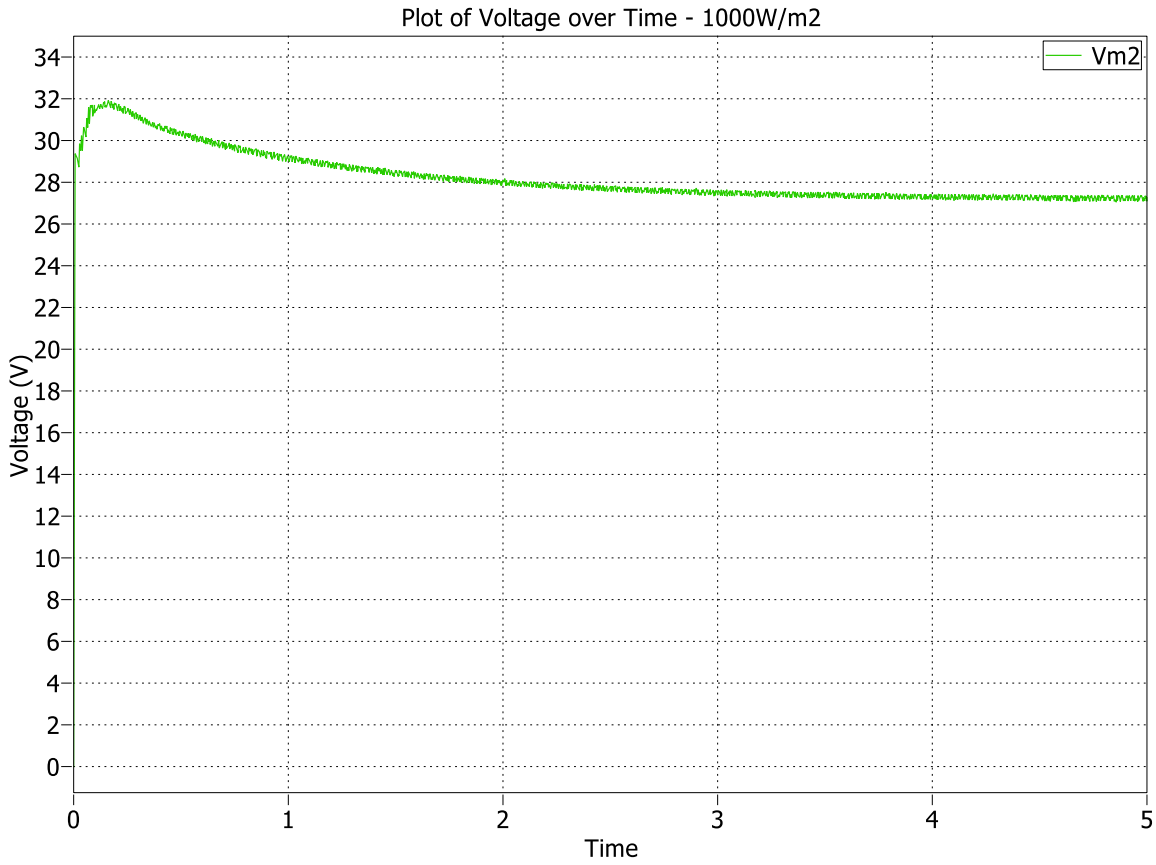

Figure 5: Plot of V_{pv} vs. Time – 1000W/m^2

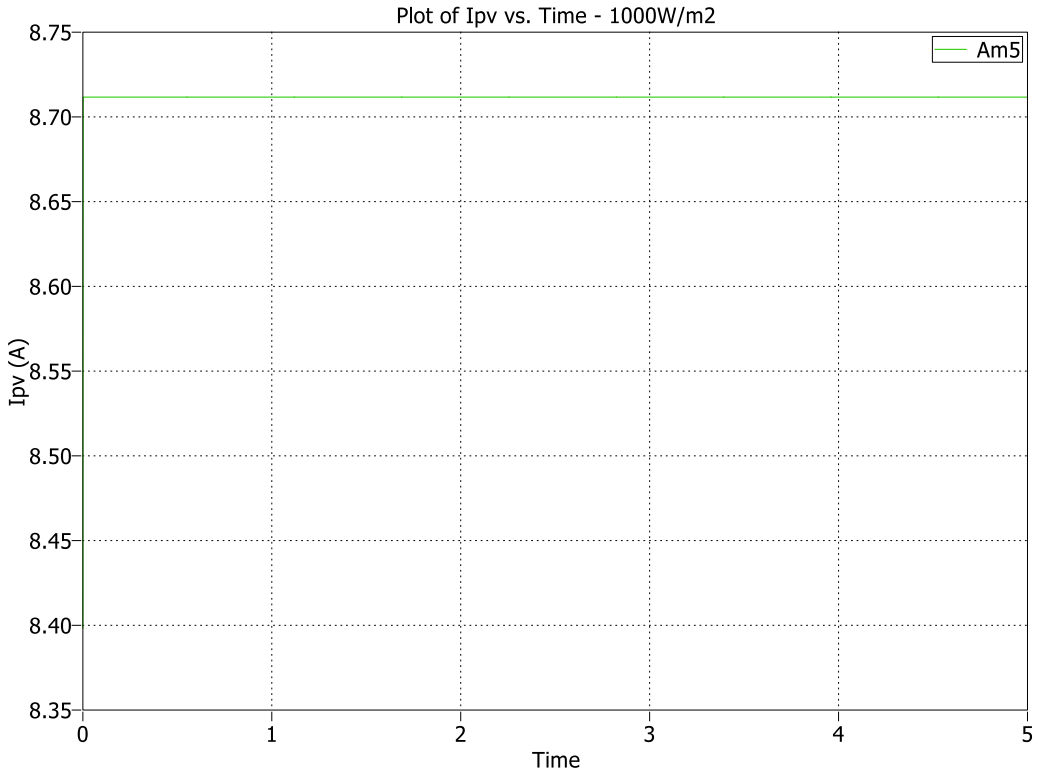

Figure 6: Plot of I_{pv} vs. Time – 1000W/m^2

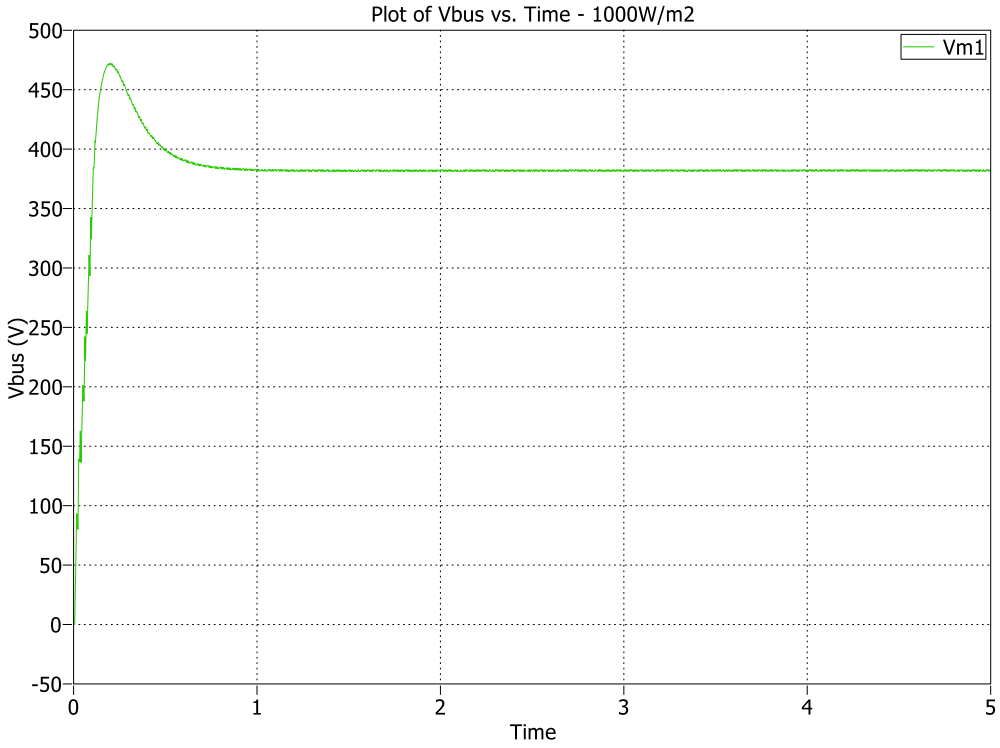

Figure 7: Plot of V_{bus} vs. Time – 1000W/m^2

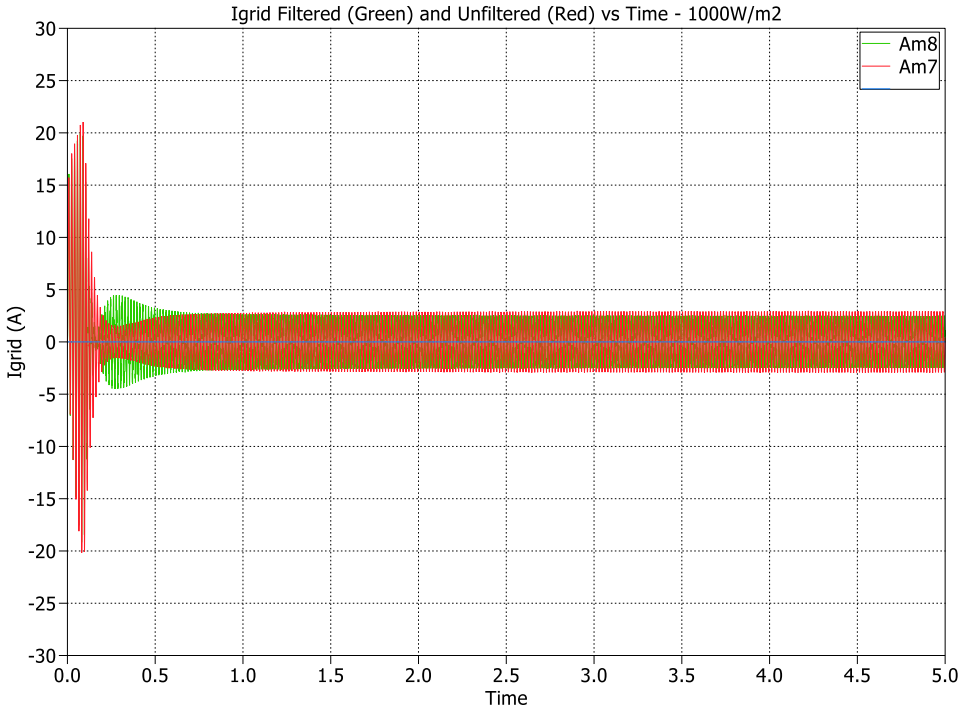

Figure 8: Plot of I_{grid} Filtered and Unfiltered vs. Time – 1000 W/m^2

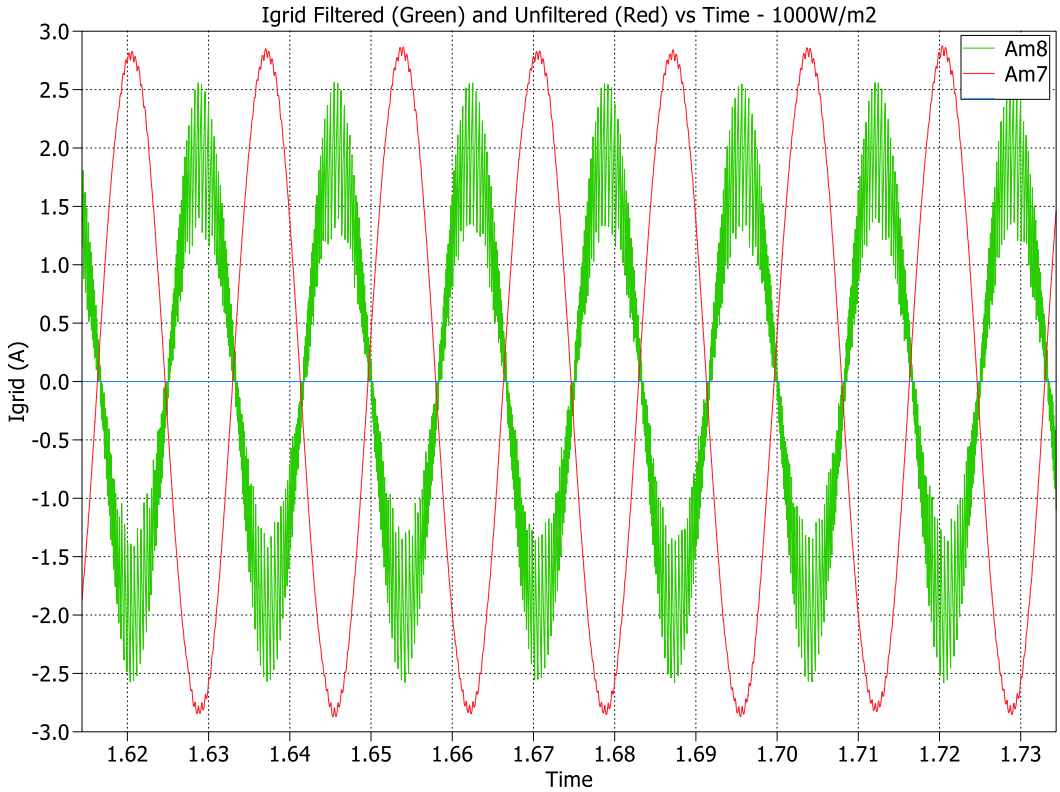

Figure 9: Close-up plot of I_{grid} Filtered and Unfiltered vs. Time – 1000 W/m^2, showing both the effect of the filter (producing a low-THD waveform) and the HCMC of the current in the unfiltered I_{grid}.

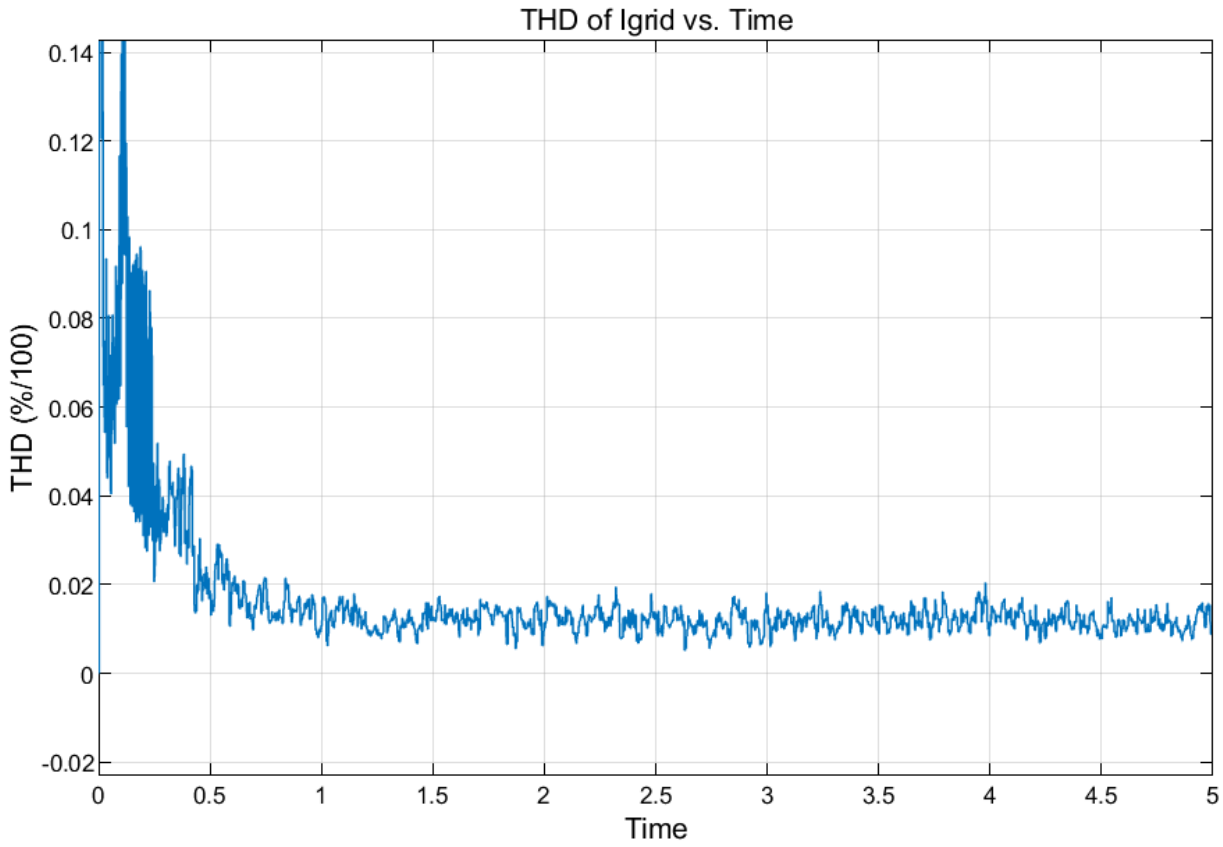

Figure 10: Plot of THD vs time for the I_{grid}. This shows that the current produced by the inverter has a very low THD (below 2%)

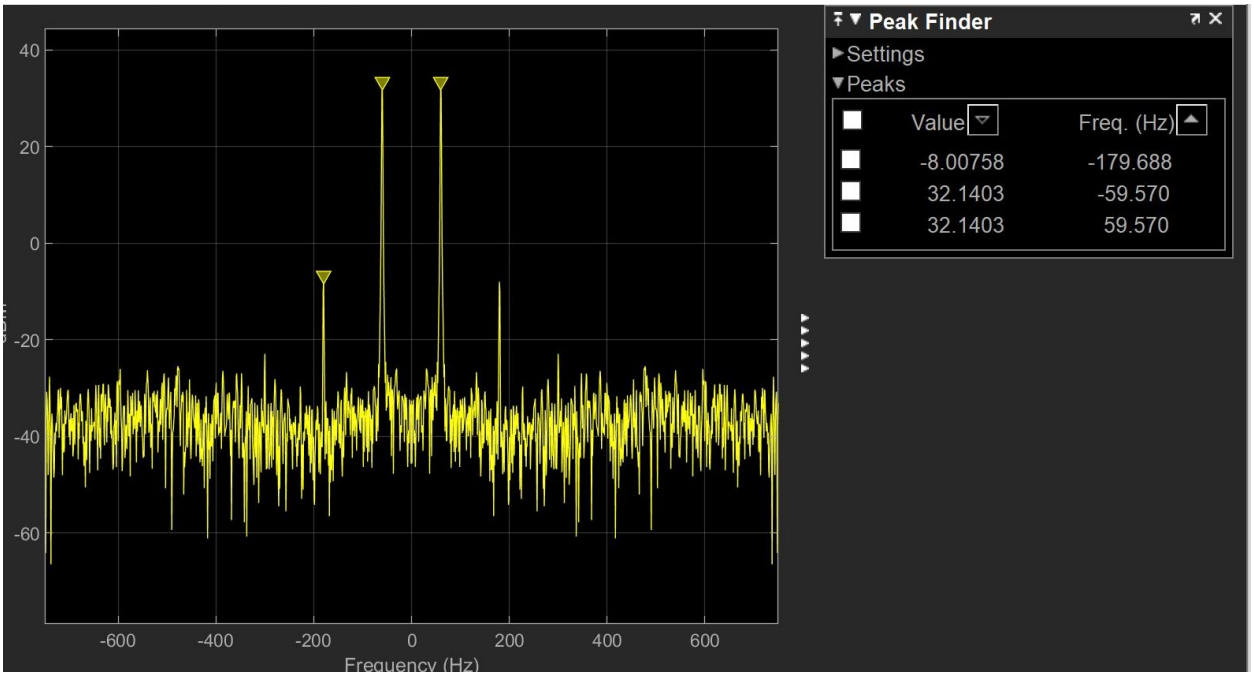

Figure 11: Spectrum of $I_{AC.}$ This shows how 60Hz is the most common frequency.

Performance at 500W/m^2

THD: 0.8%

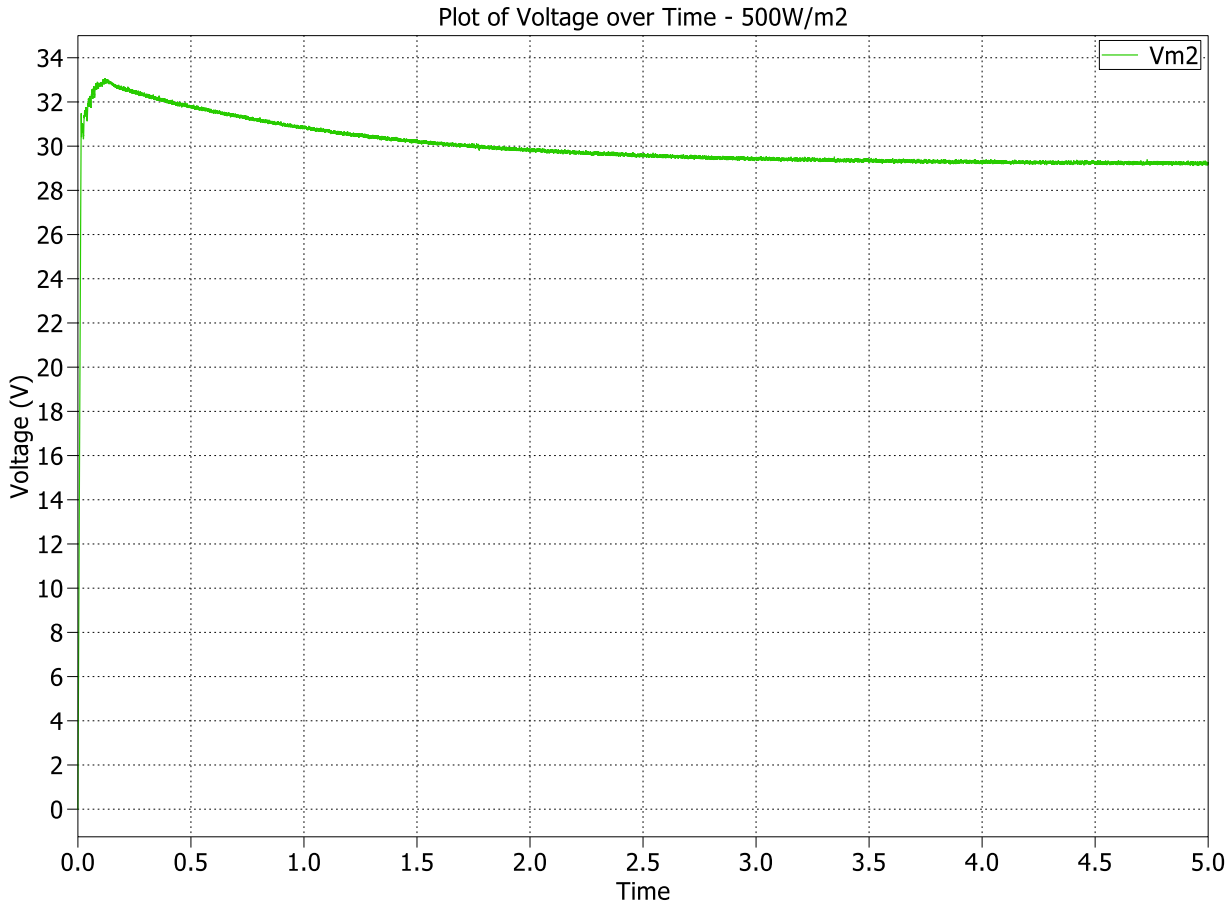

Figure 12: Plot of V_{pv} vs. Time – 500W/m^2

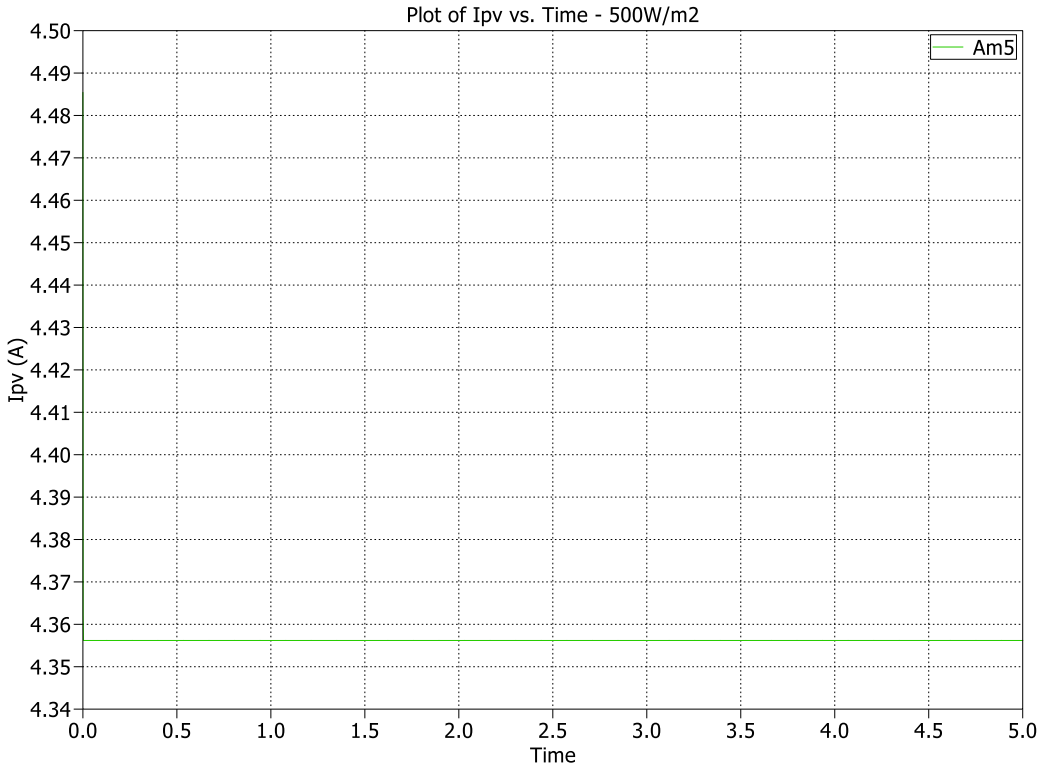

Figure 13: Plot of I_{pv} vs. Time – 500W/m^2

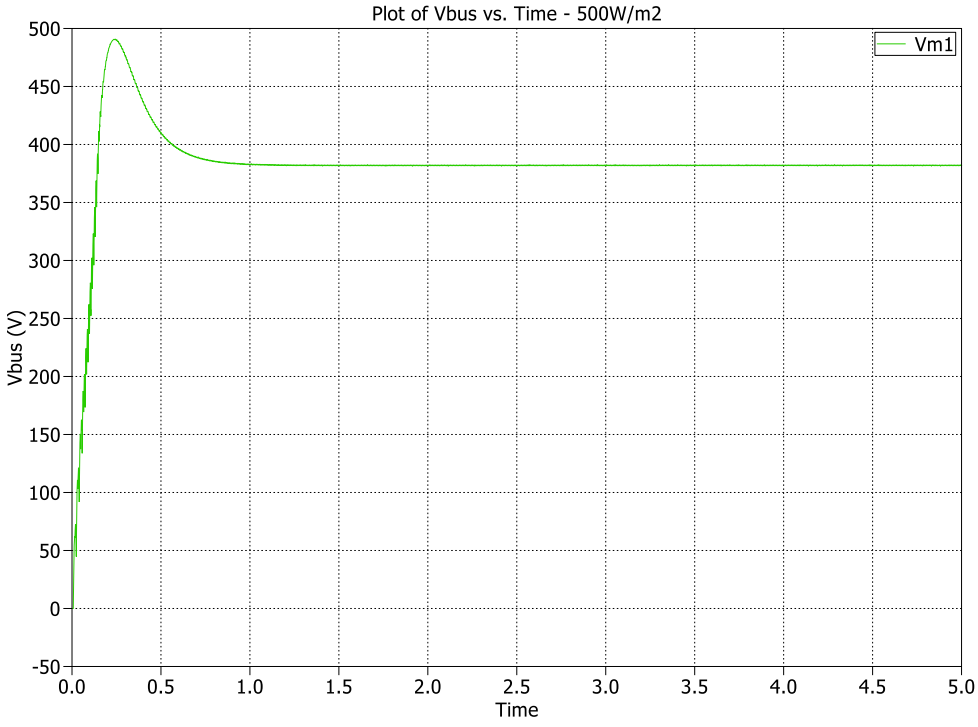

Figure 14: Plot of V_{bus} vs. Time – 500W/m^2

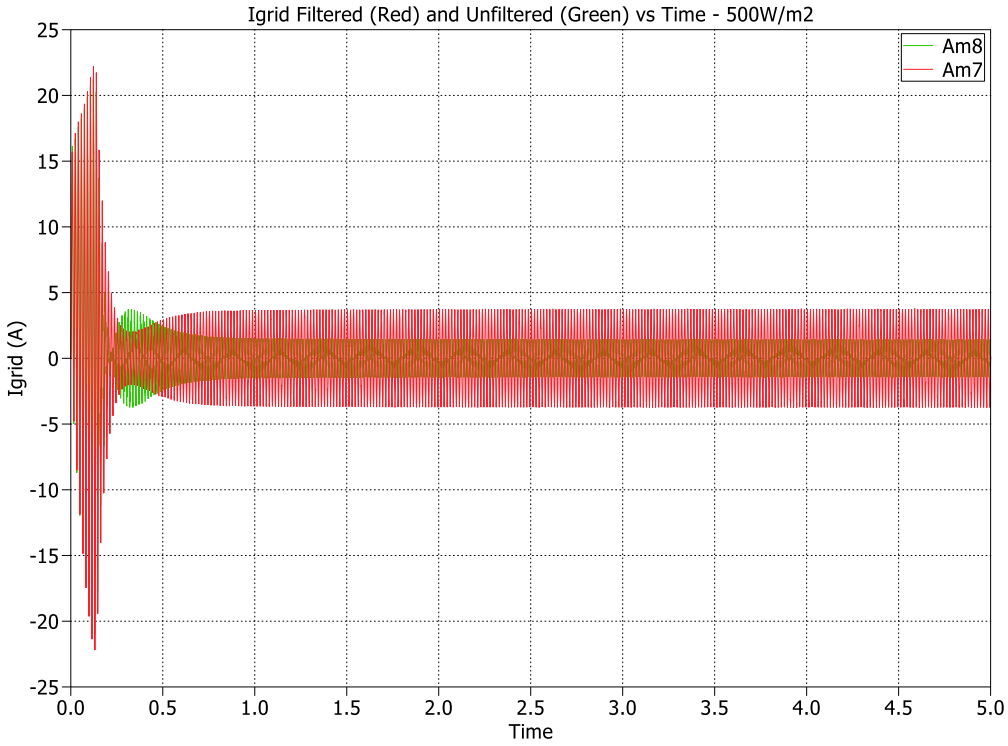

Figure 15: Plot of I_{grid} Filtered and Unfiltered vs. Time – 500 W/m^2

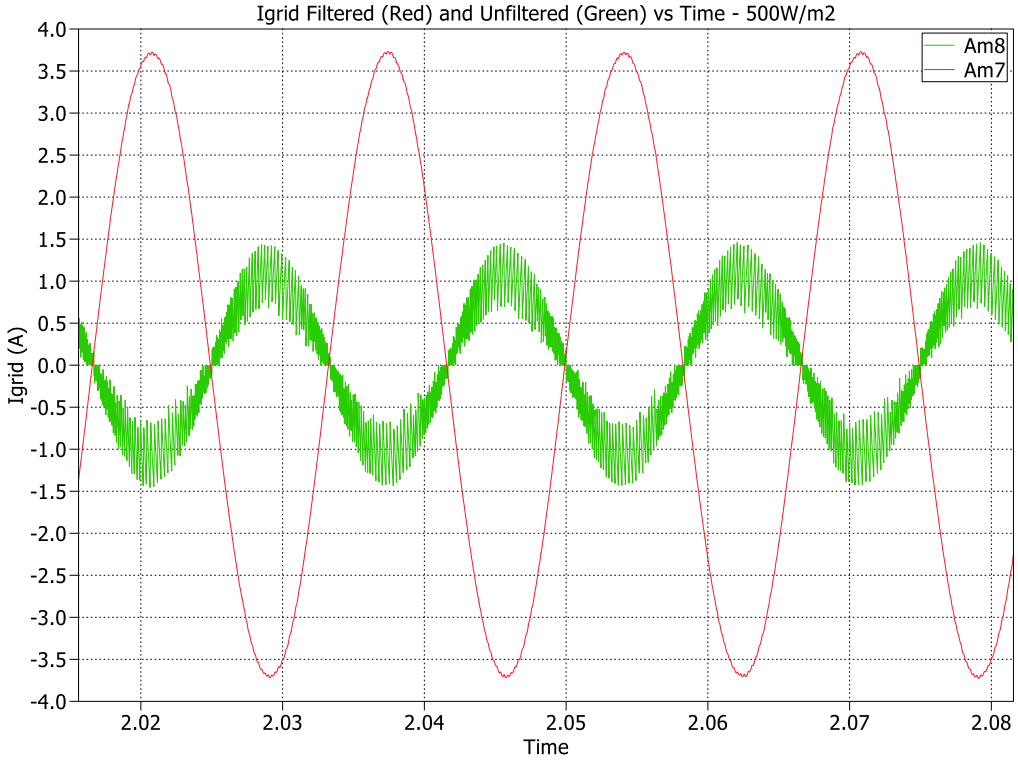

Figure 16: Close-up plot of I_{grid} Filtered and Unfiltered vs. Time – 500 W/m^2, showing both the effect of the filter (producing a low-THD waveform) and the HCMC of the current in the unfiltered $I_{grid.}$ The filter also makes the filtered I_{grid} in phase with the AC voltage.

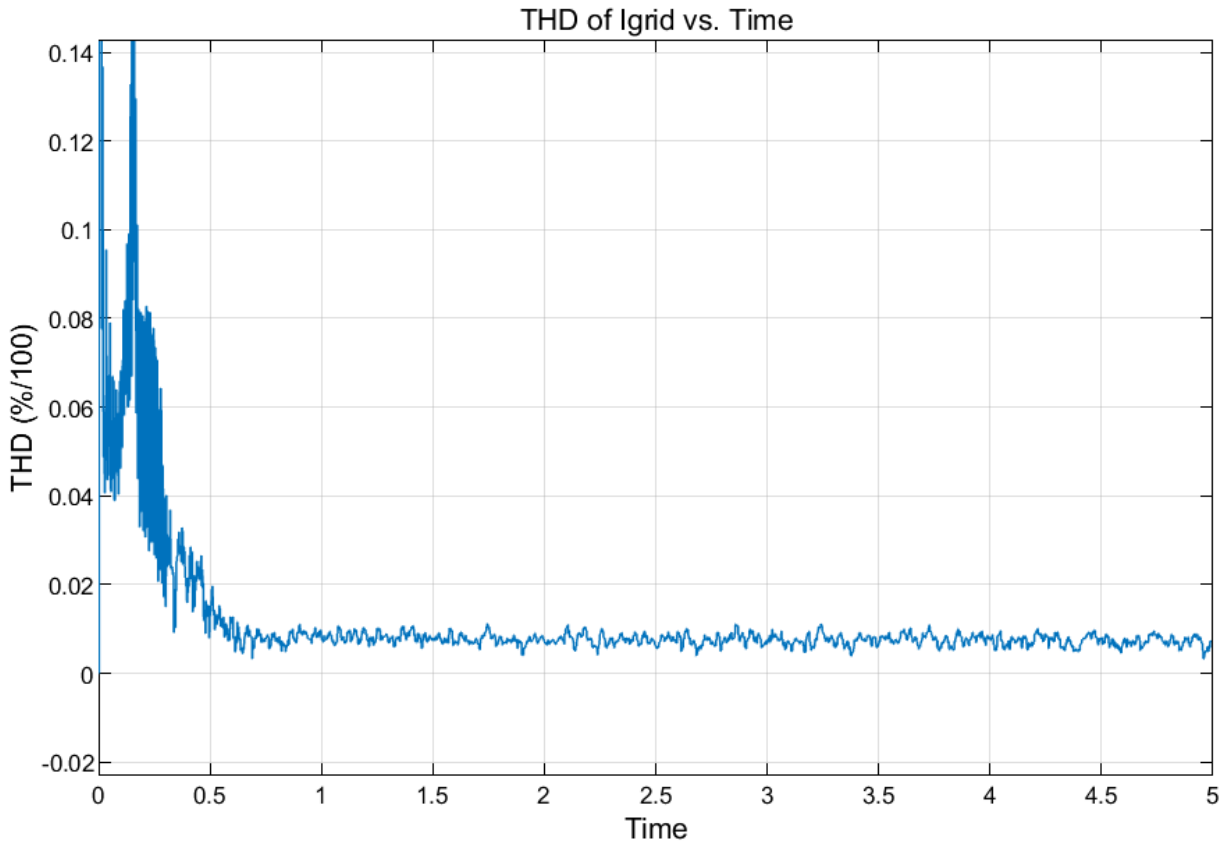

Figure 17: Plot of THD vs time for the I_{grid}. This shows that the current produced by the inverter has a very low THD (below 1%)

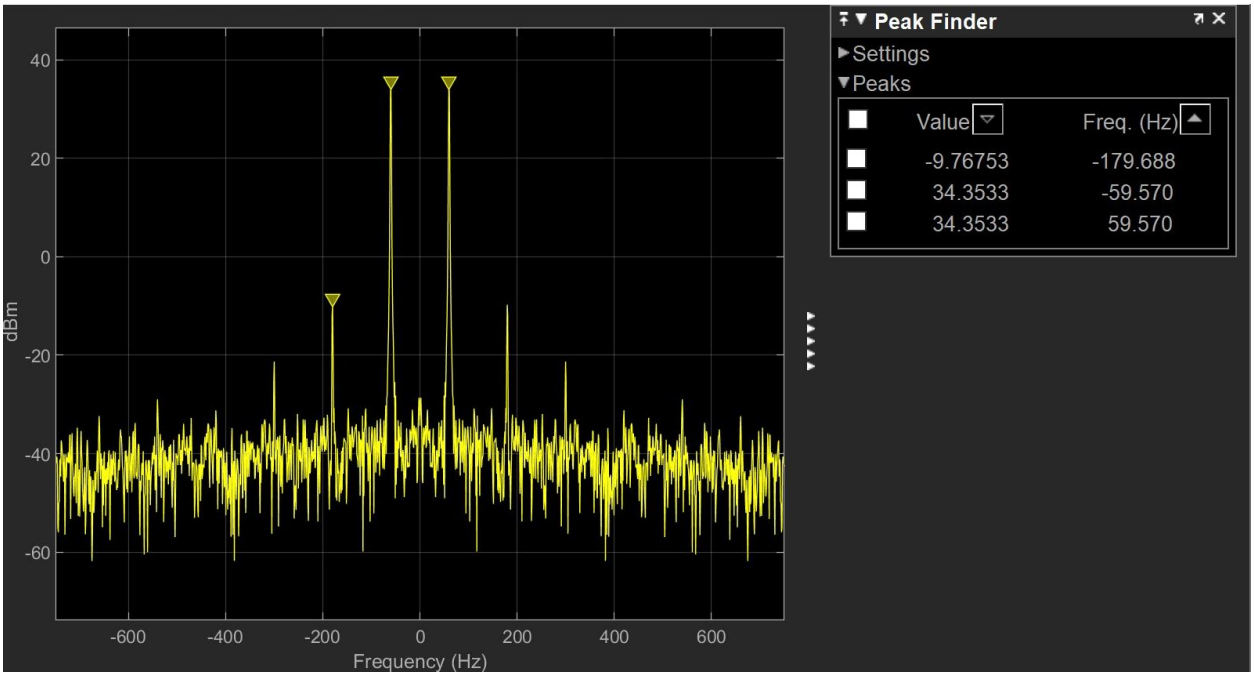

Figure 18: Spectrum of $I_{AC.}$ This shows how 60Hz is the most common frequency.

Performance at 200 W/m^2

THD: 0.5%

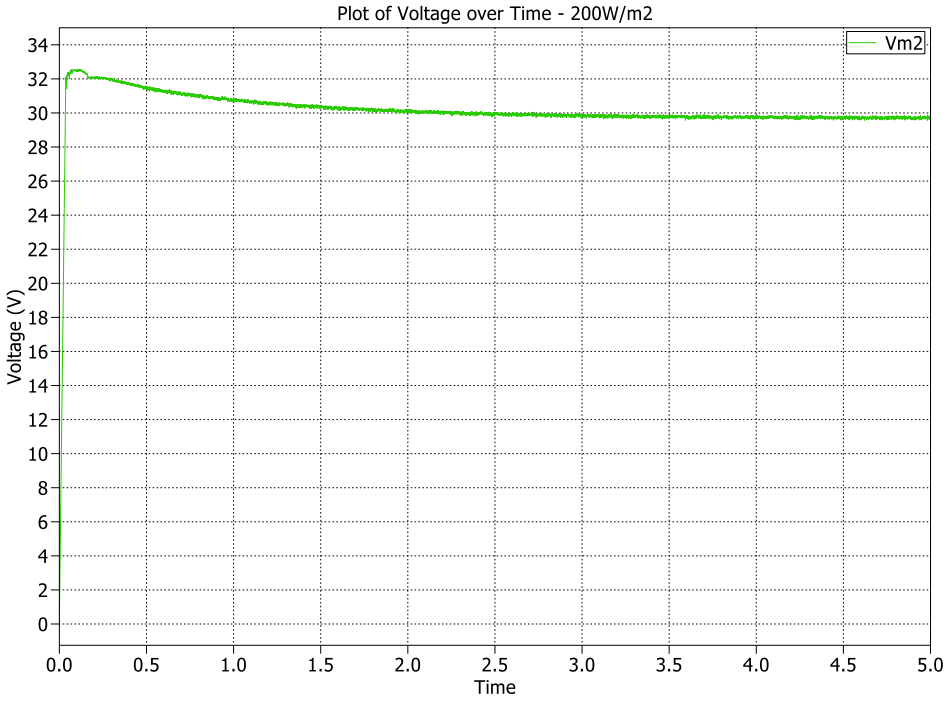

Figure 19: Plot of V_{pv} vs. Time – 200W/m^2

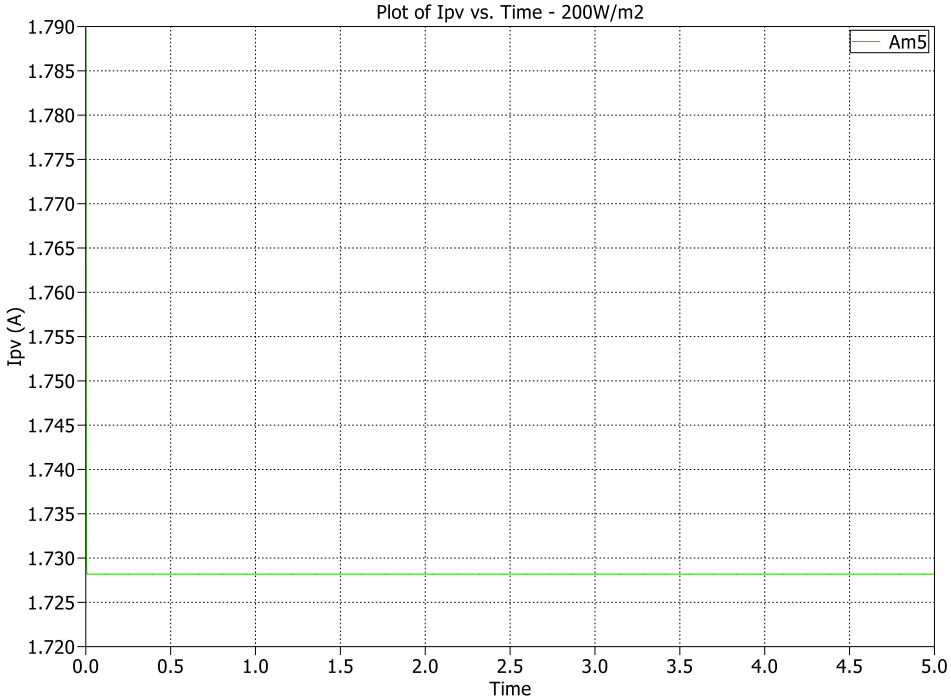

Figure 20: Plot of I_{pv} vs. Time – 200W/m^2

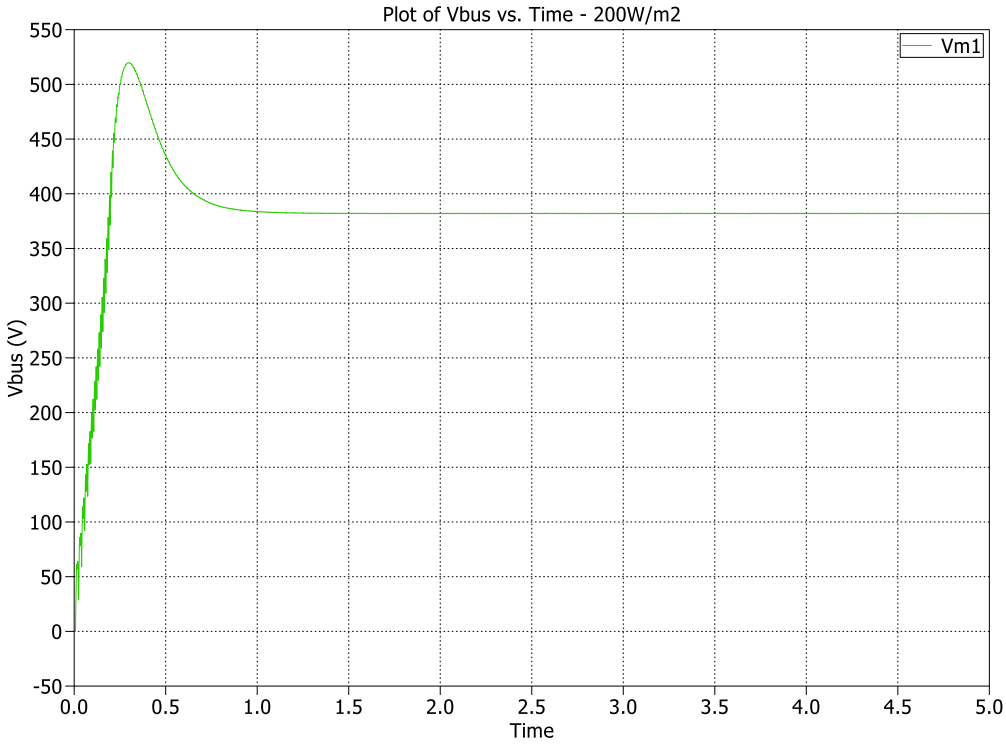

Figure 21: Plot of V_{bus} vs. Time – 200W/m^2

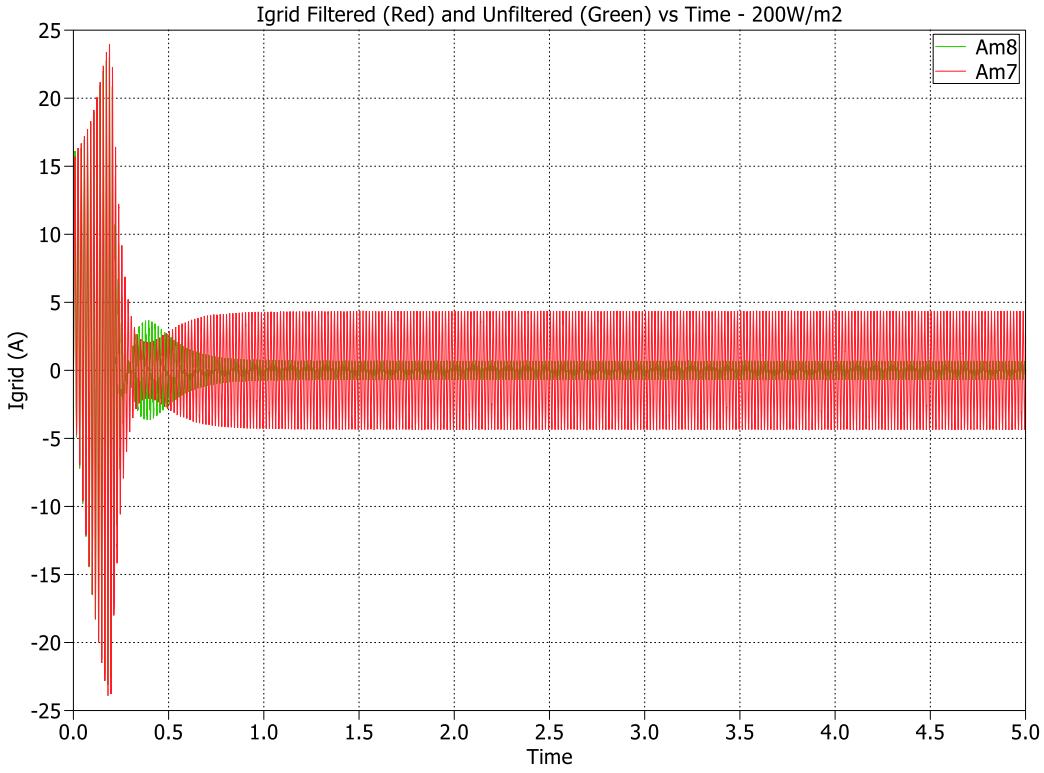

Figure 22: Plot of I_{grid} Filtered and Unfiltered vs. Time – 200 W/m^2

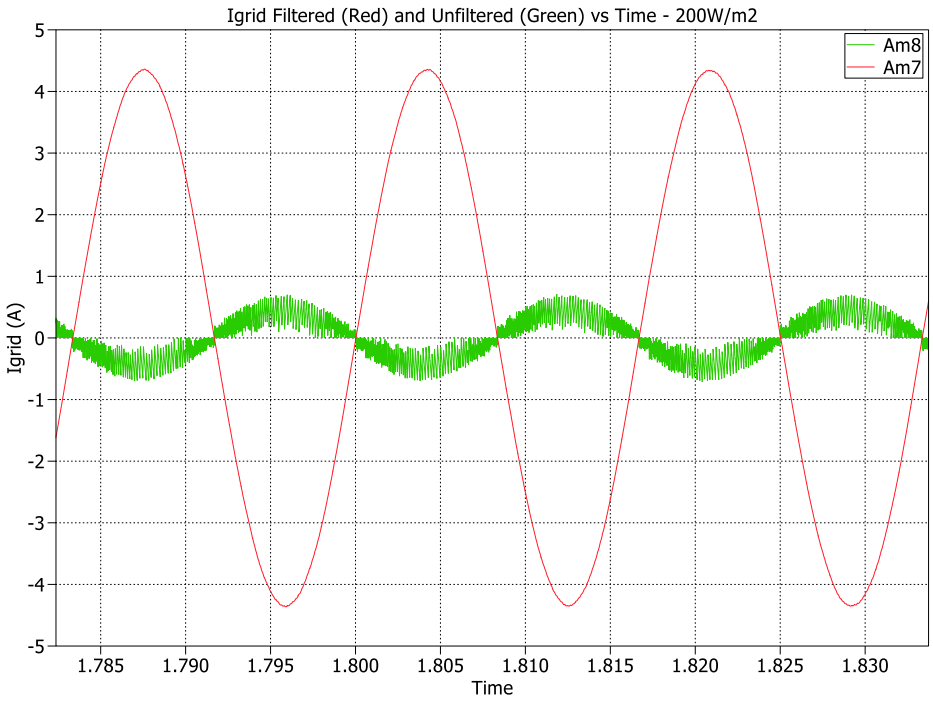

Figure 23: Close-up plot of I_{grid} Filtered and Unfiltered vs. Time – 200 W/m^2, showing both the effect of the filter (producing a low-THD waveform) and the HCMC of the current in the unfiltered I_{grid}.

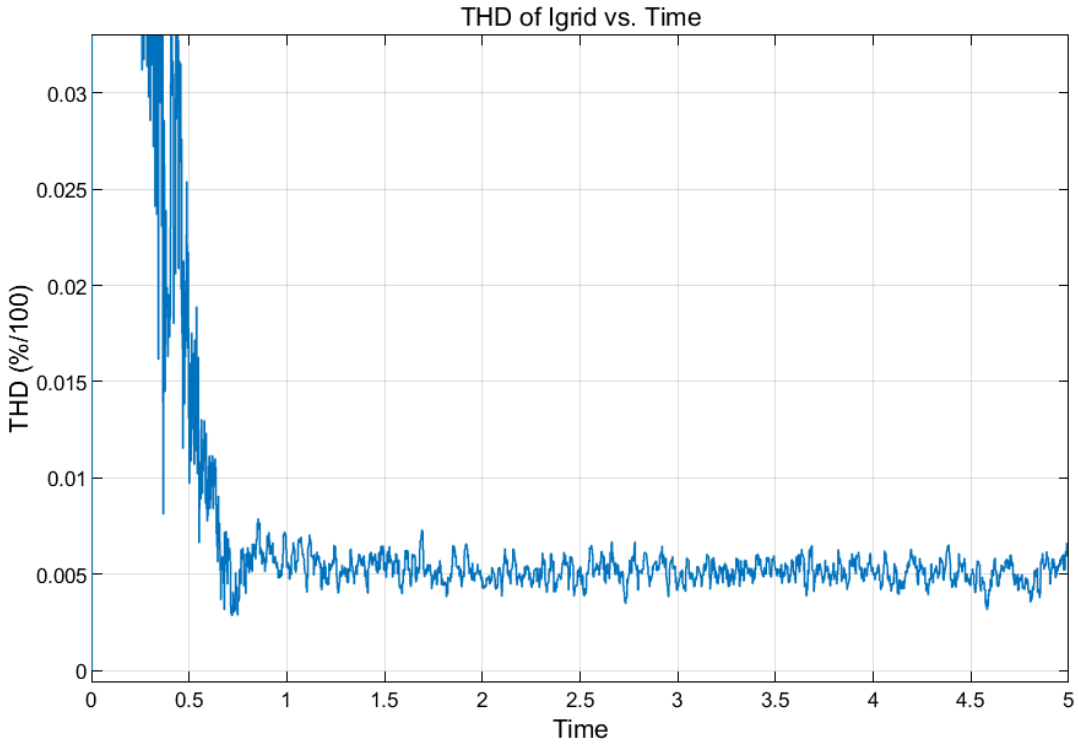

Figure 24: Plot of THD vs time for the I_{grid}. This shows that the current produced by the inverter has a very low THD (about 0.5%)

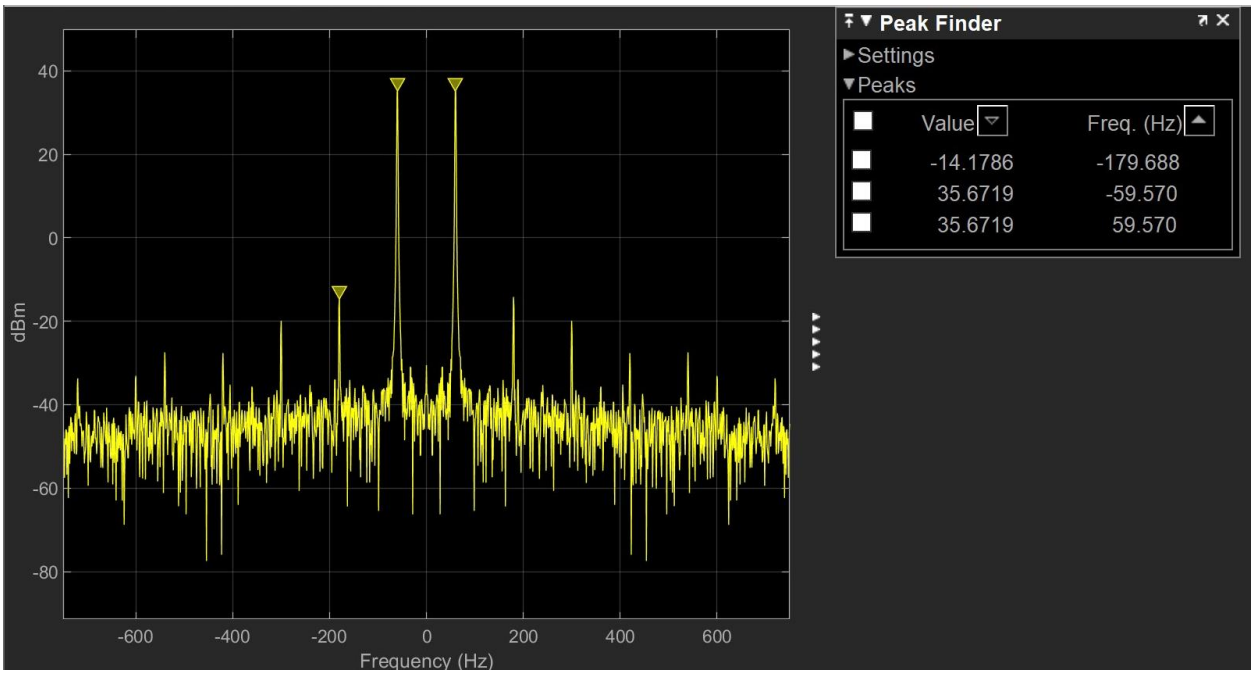

Figure 25: Spectrum of $I_{AC.}$ This shows how 60Hz is the most common frequency.

Part E: Transient Tests

Change from 150W/m^2 to 1000W/m^2 at t=1

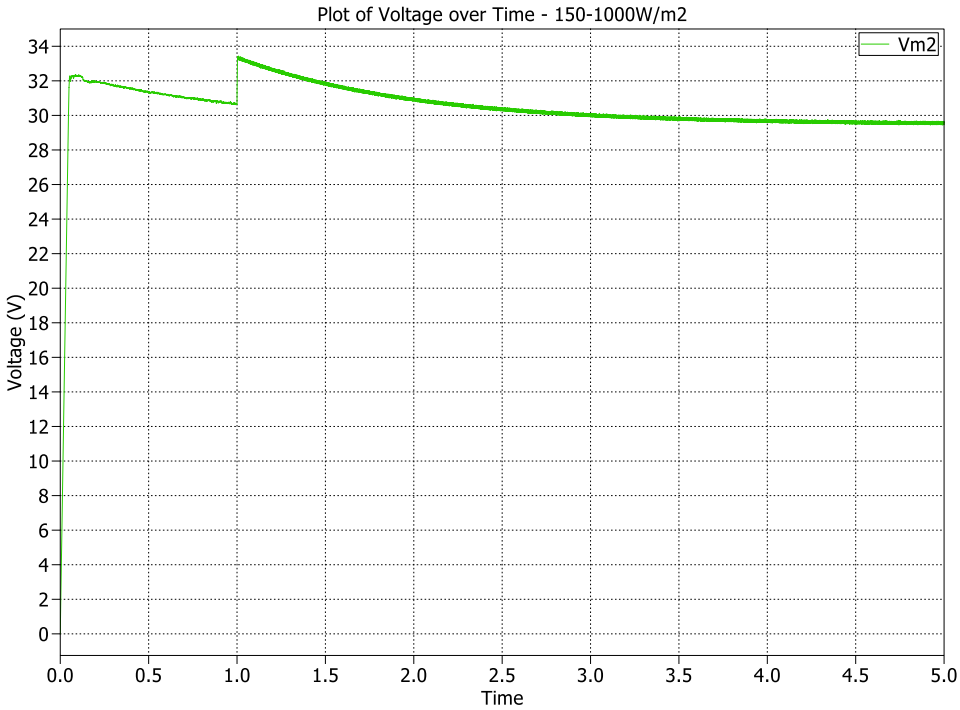

Figure 26: Plot of V_{pv} vs. Time – 500W/m^2. This shows how the PV voltage reacts as the panel voltage increases.

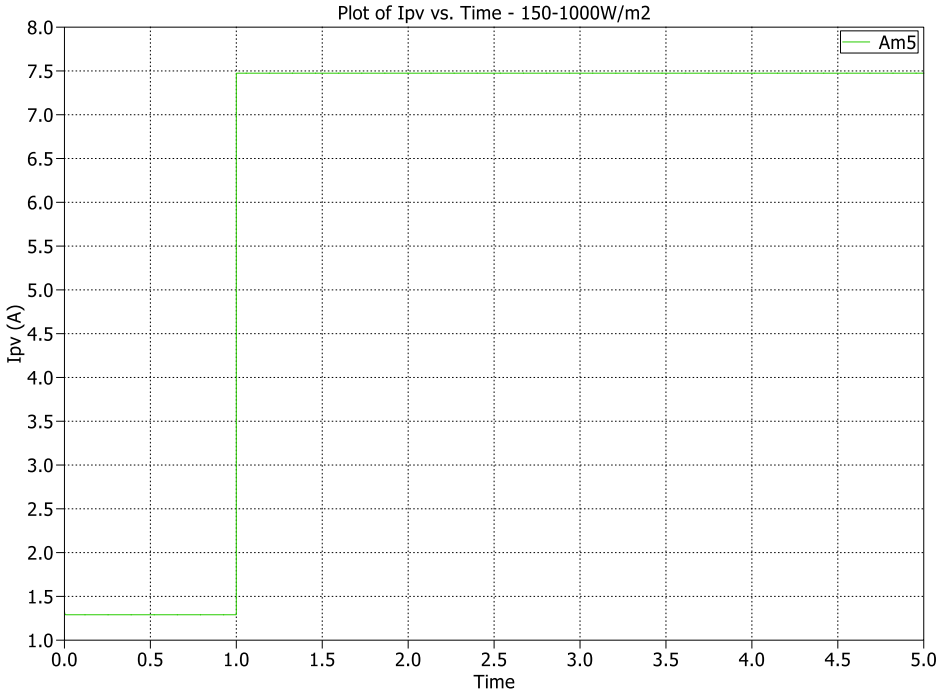

Figure 27: Plot of I_{pv} vs. Time – 150-1000W/m^2. This shows how the PV current jumps as the irradiance increaes.

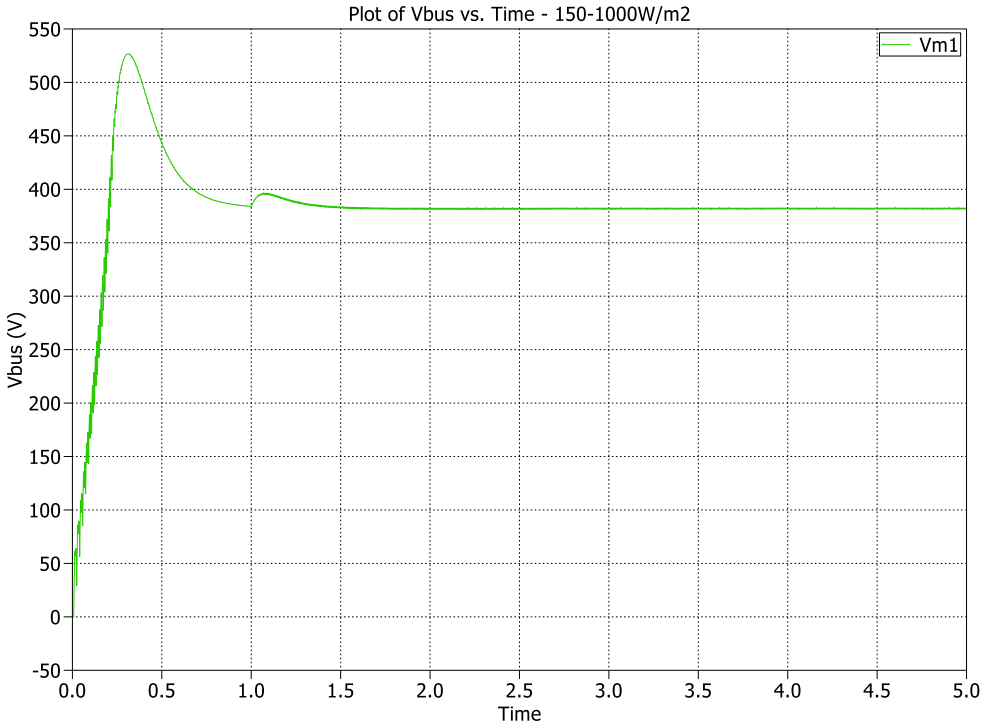

Figure 28: Plot of V_{bus} vs. Time – 150-1000W/m^2. This shows a slight increase to V_{bus} which is quickly resolved.

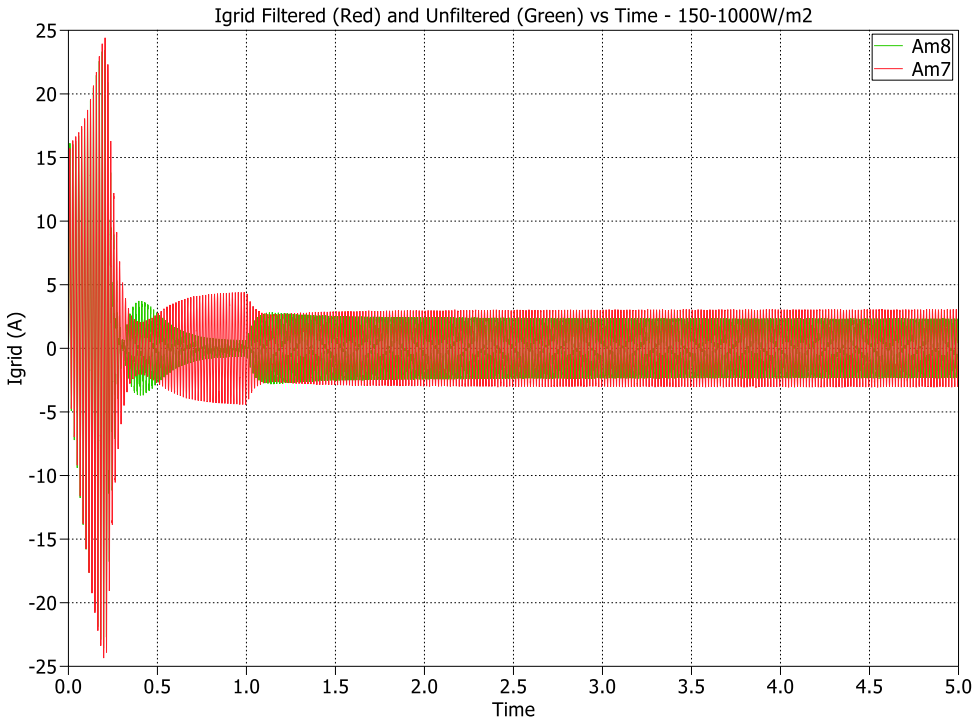

Figure 29: Plot of I_{grid} Filtered and Unfiltered vs. Time – 150-1000 W/m^2

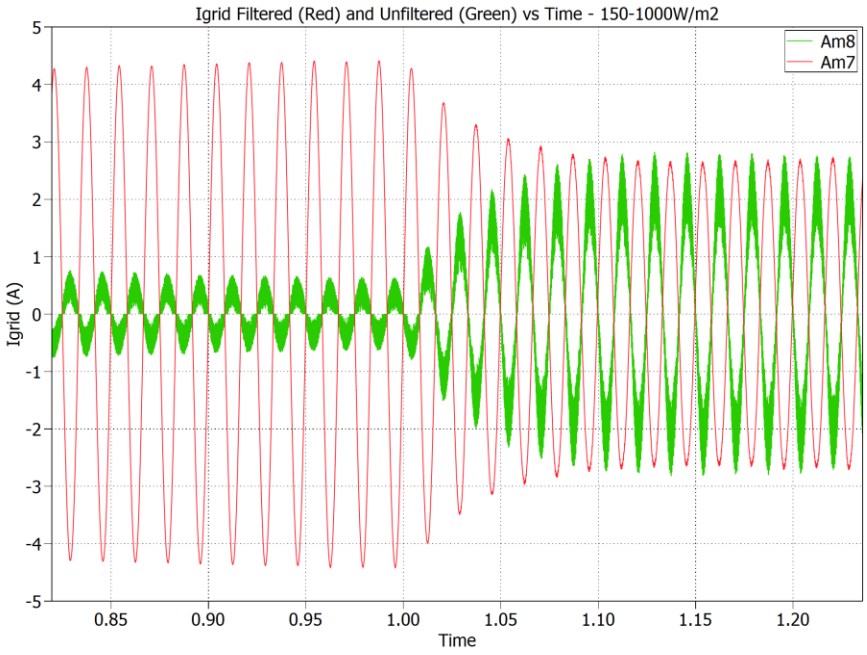

Figure 29: Close-up plot of I_{grid} Filtered and Unfiltered vs. Time – 150-1000W/m^2, showing both the effect of the filter (producing a low-THD waveform) and the HCMC of the current in the unfiltered I_{grid}. This also shows how the current reacts to the step in irradiance.

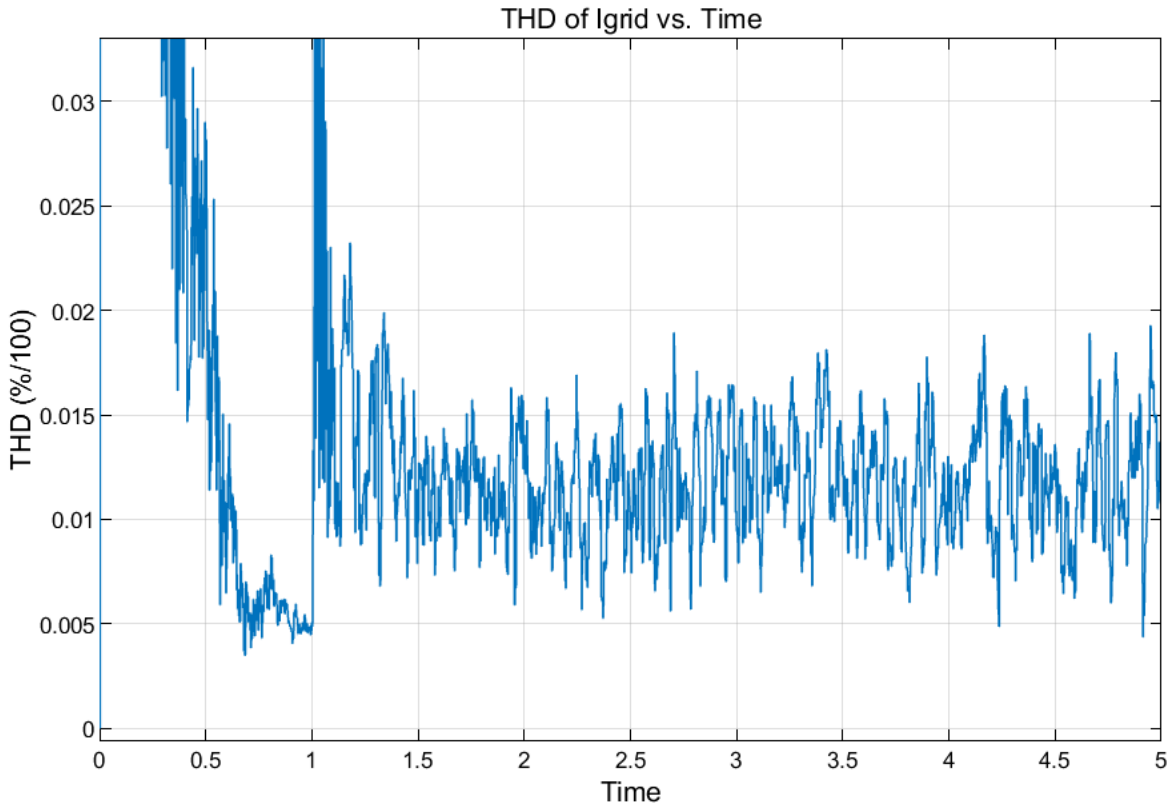

Figure 30: Plot of THD vs. Time. This shows how the THD of the current waveform jumps from 0.5% to 1.5% as the solar irradiance increases.

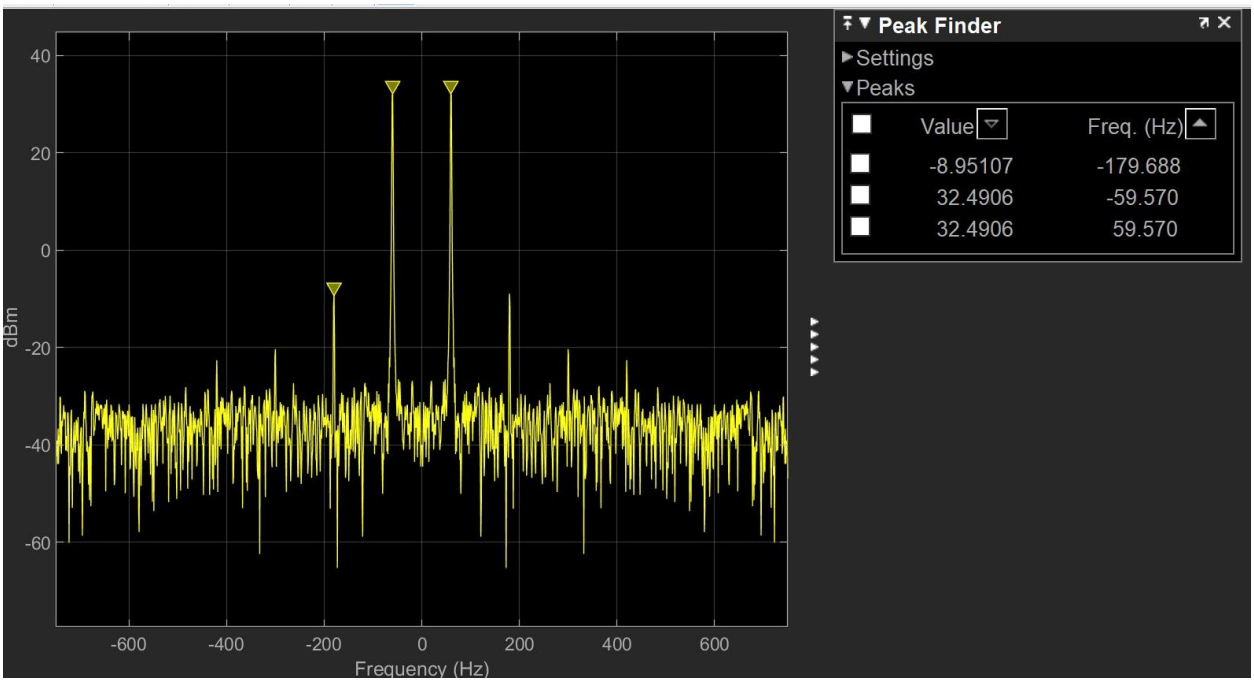

Figure 31: Spectrum of $I_{AC.}$ This shows how 60Hz is the most common frequency.

Step in V_{grid} from 220V to 245 V at t = 1.5

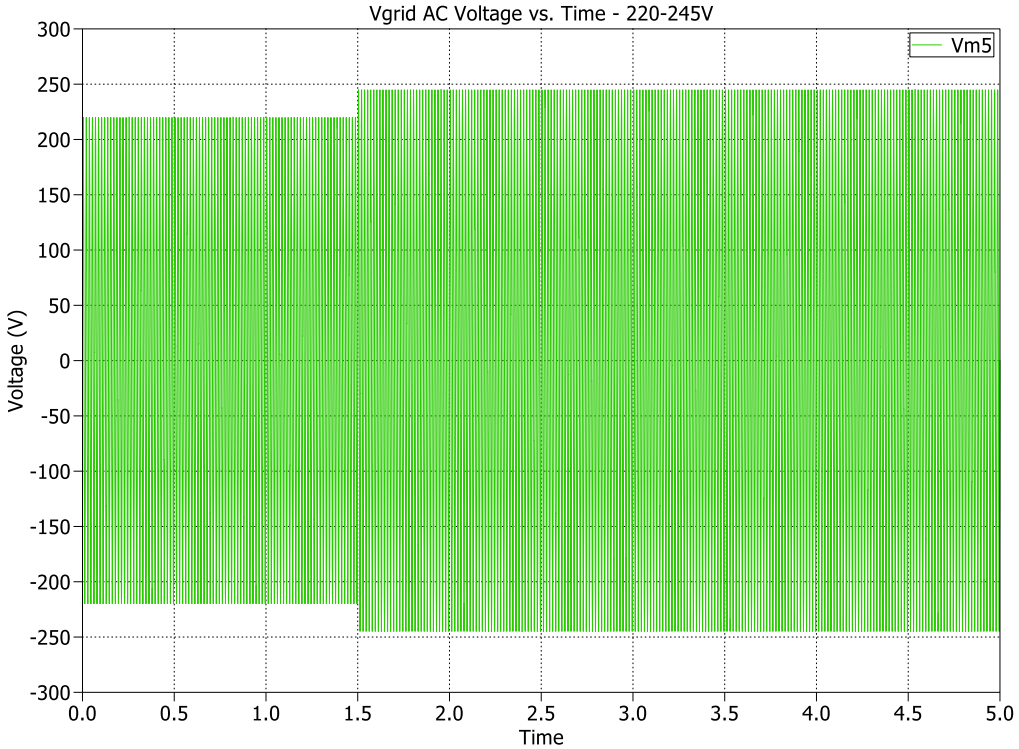

Figure 32: Plot of V_{grid} vs. time, depicting the increase from 220V to 245V at t=1.5

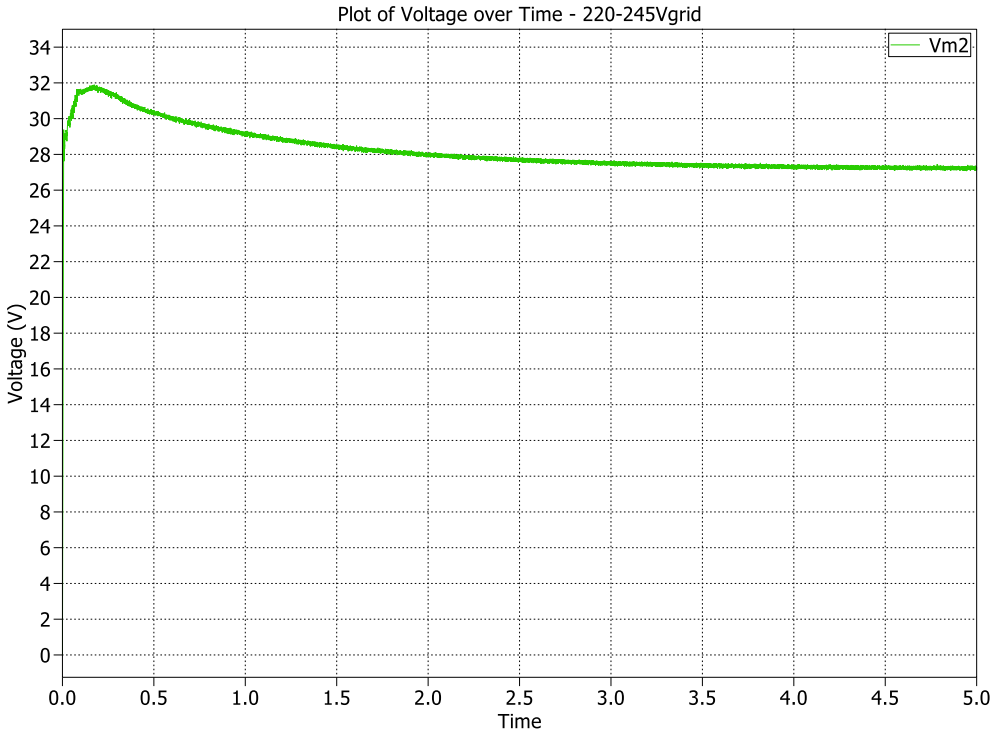

Figure 33: Plot of V_{pv} vs. time – 220-245V, showing how the PV voltage is unaffected by a change in V_{grid}.

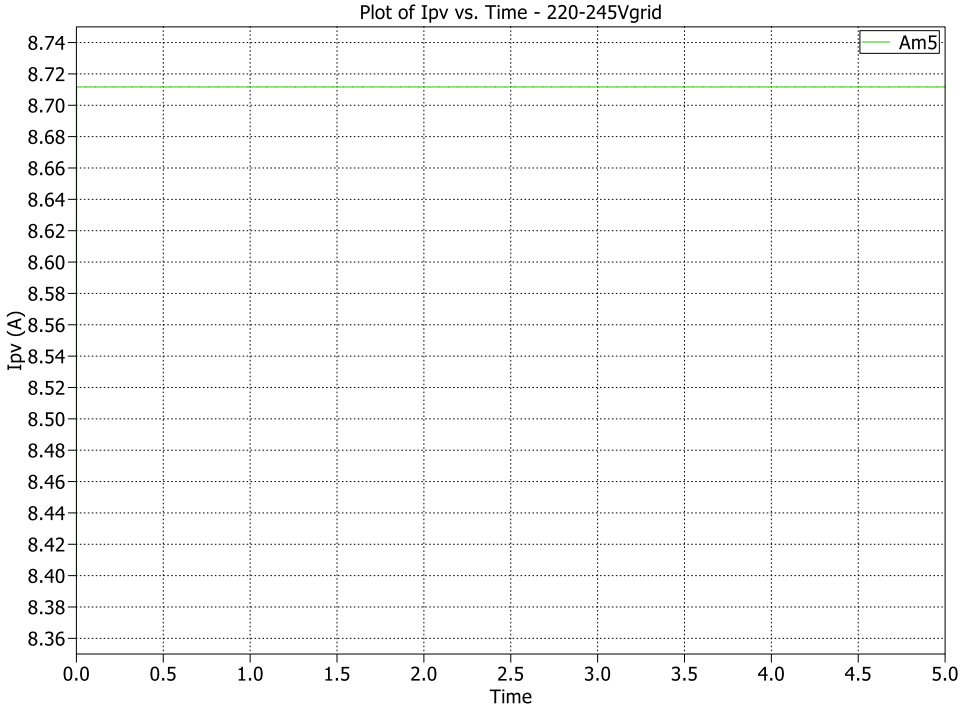

Figure 33: Plot of I_{pv} vs. time – 220-245V, showing how the PV current is unaffected by a change in V_{grid}.

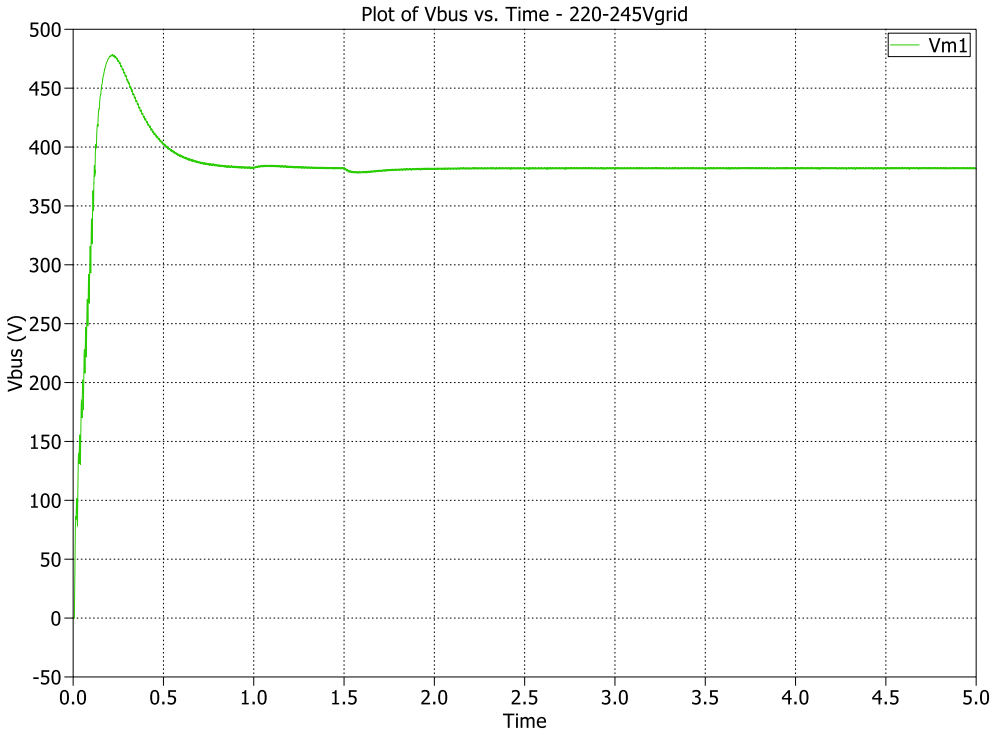

Figure 34: Plot of V_{bus} vs. Time – 220-245V. This shows a slight decrease to V_{bus} which is quickly resolved.

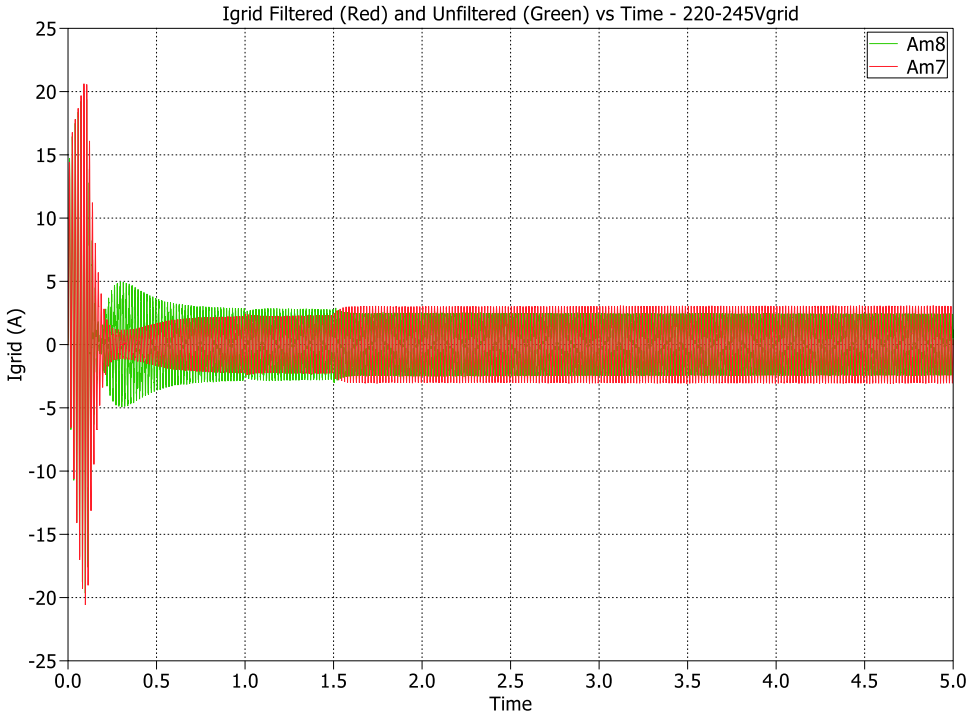

Figure 35: Plot of I_{grid} Filtered and Unfiltered vs. Time – 220-245V

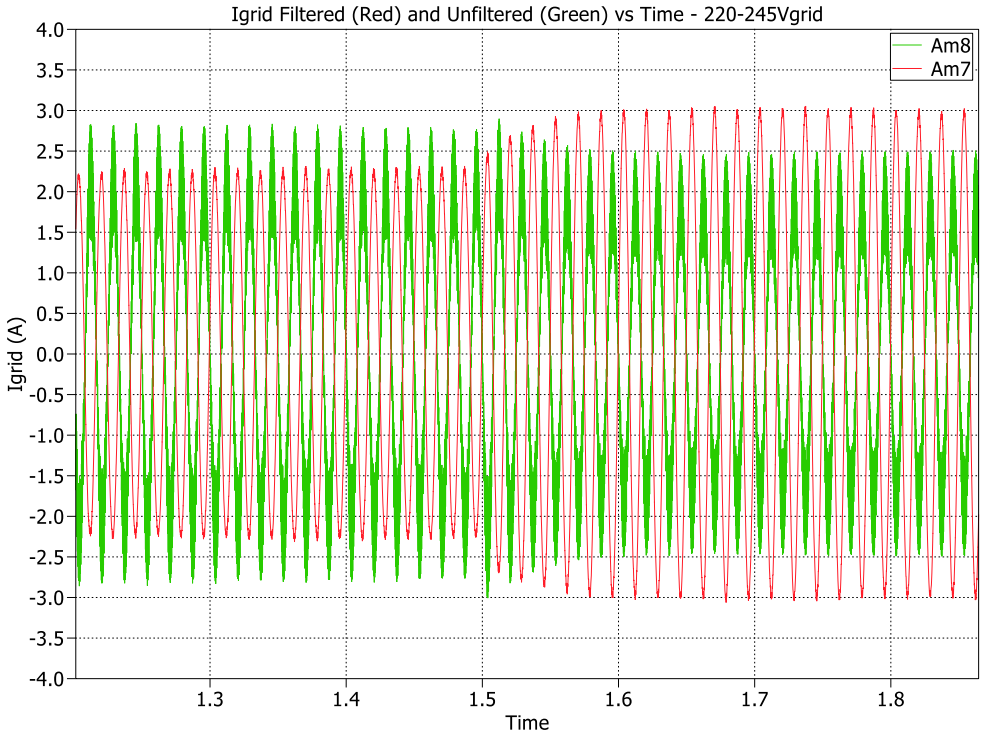

Figure 36: Close-up plot of I_{grid} Filtered and Unfiltered vs. Time – 220-245V, showing both the effect of the filter (producing a low-THD waveform) and the HCMC of the current in the unfiltered I_{grid}. This also shows how the current reacts to the step in V_{grid}.

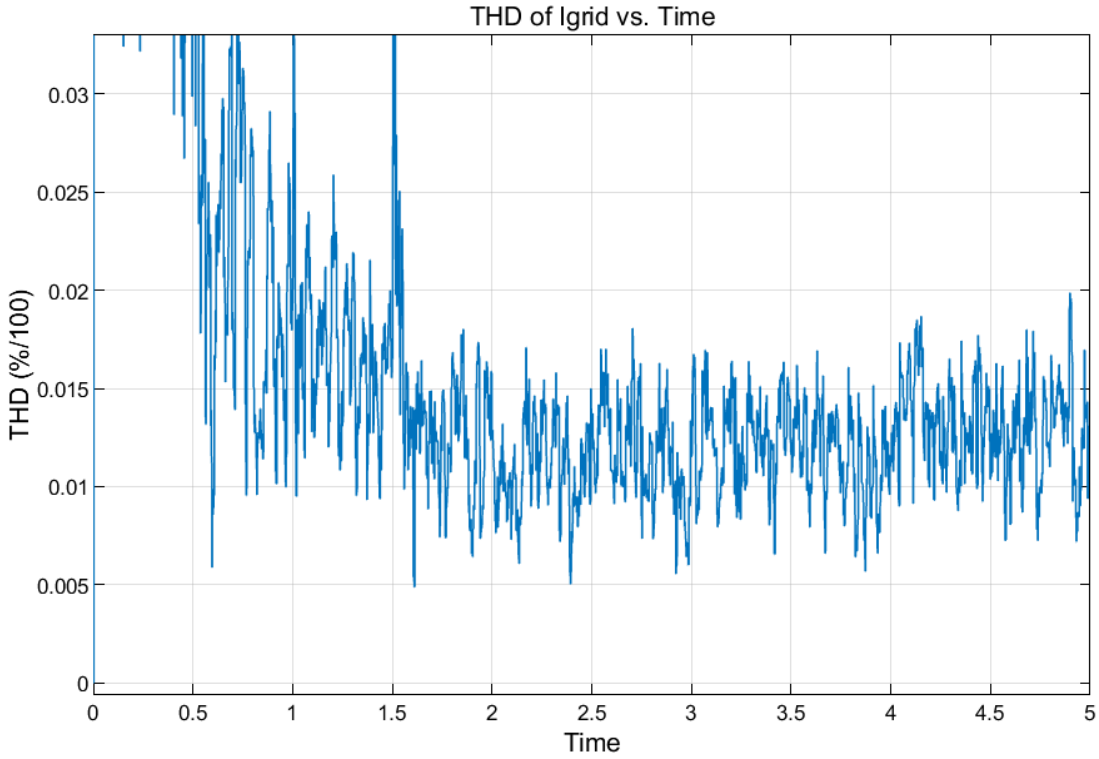

Figure 37: Plot of THD vs. Time. This shows how the THD of the current waveform decreases from 1.5% to 1.25% as the solar irradiance increases.

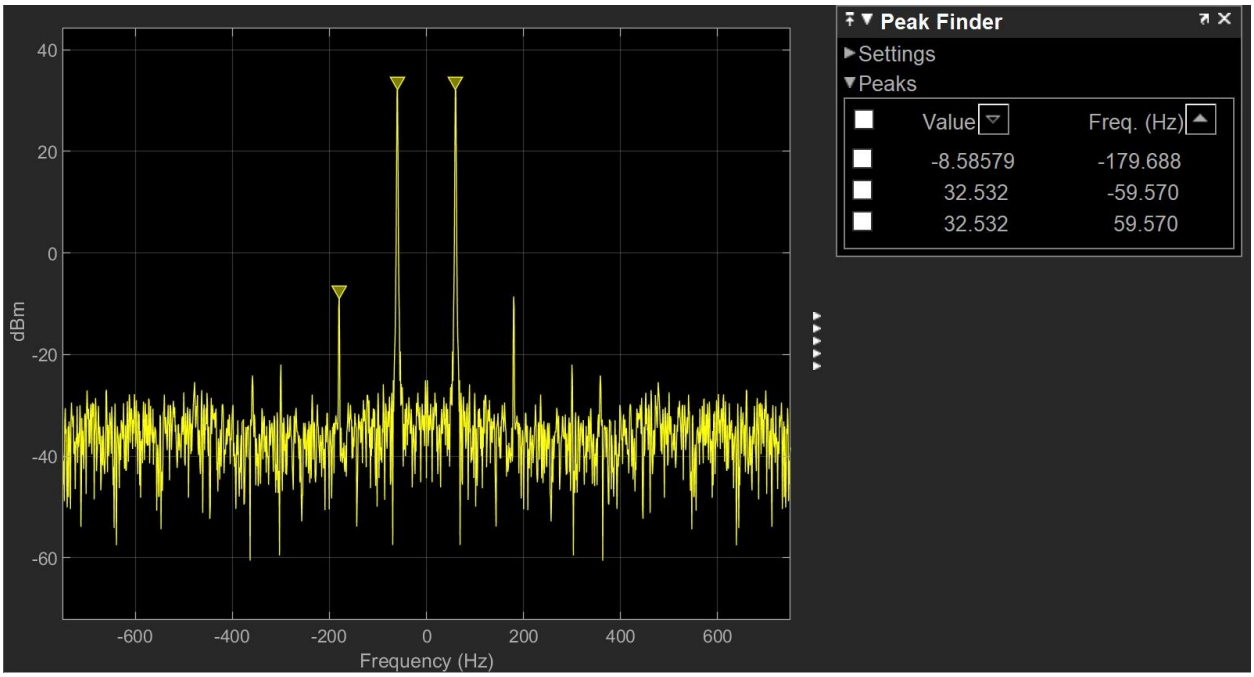

Figure 38: Spectrum of $I_{AC.}$ This shows how 60Hz is the most common frequency.

Part F: Reporting Results

Description	Parameter	Value	Unit
Input Capacitance	C_{in}	2000	uF
Bus capacitance	C_{bus}	1200	uF
Total volume of capacitance in the MIV	V_{cap}	3.93	cm^3
Switching Frequency in Flyback Stage	F_{s1}	10	kHz
Switching Frequency in Inverter Stage	F_{s2}	400	kHz
Magnetizing inductance for flyback transformers	L_m	50	uH
Bus Voltage	V_{bus}	382	V
Peak Magnetizing current for flyback transformers	I_{pk}	20	A
Turns ratio	N	1:20	
Peak to peak voltage ripple at V_{pv}	dV_{pv}	0.2	V
MPPT Efficiency	n_{mppt}	87%	%
Output current THD @ 1000 W/m^2	I_{THD}	1.5	%
Output current THD @ 500 W/m^2	I_{THD}	0.8	%
Output current THD @ 200 W/m^2	I_{THD}	0.5	%

Full Simulation Screenshots

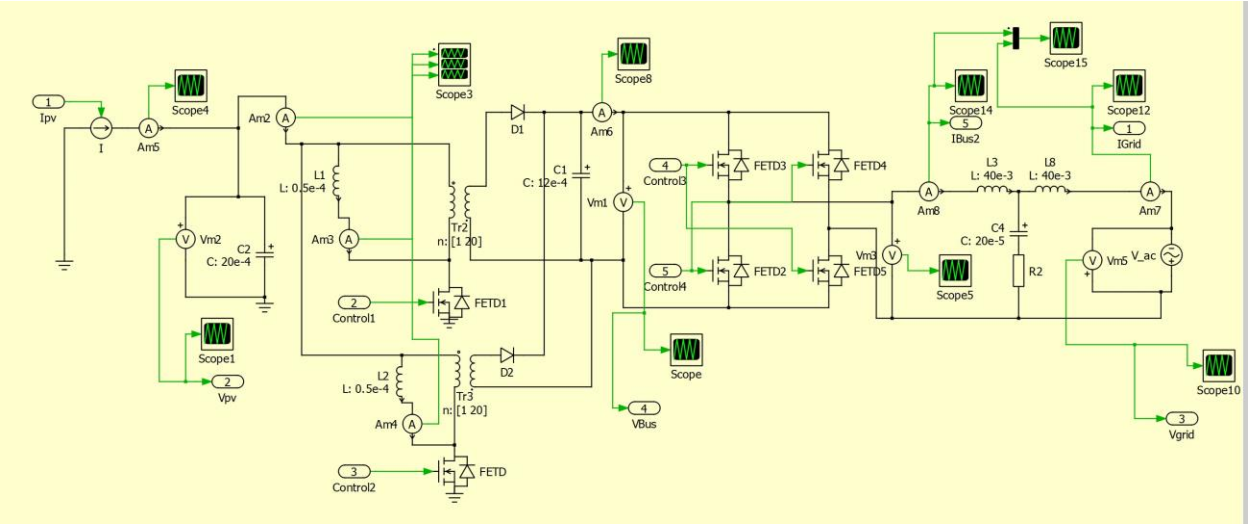

Figure 39: Screenshot of the PLECS portion of the assignment

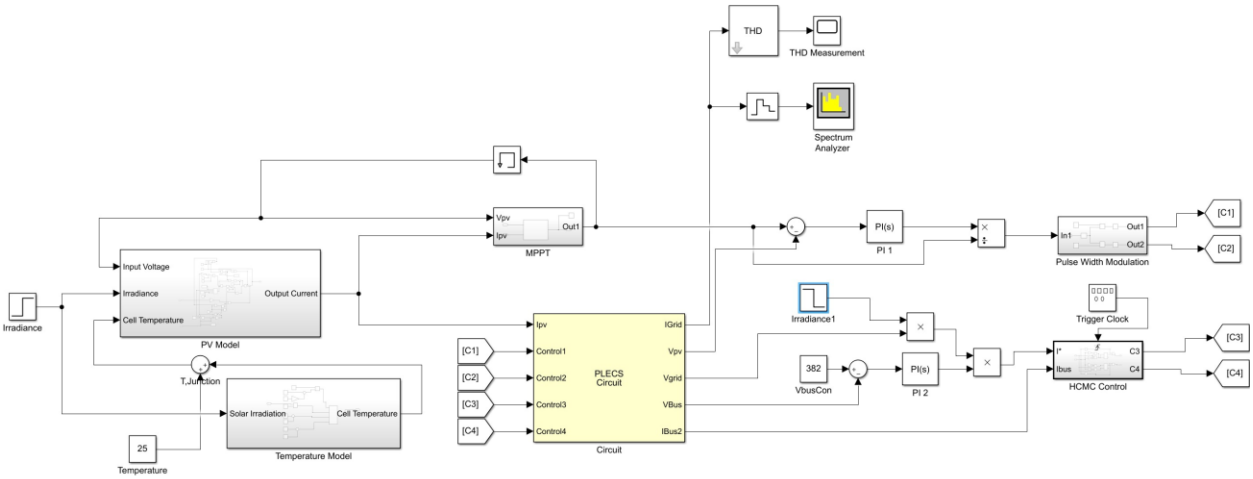

Figure 40: Screenshot of the Simulink portion of the assignment