Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

Course Title:	Power Electronics
Course Number:	ELE504
Semester/Year (e.g.F2016)	F2021

Instructor:	Sandeep Kaler

Assignment/Lab Number:	Project
Assignment/Lab Title:	Design Project

Submission Date:	2021-11-07
Due Date:	2021-11-07

Student LAST Name	Student FIRST Name	Student Number	Section	Signature*
Ahsan	Abrar	500722182	01	Abrar Ahsan

*By signing above you attest that you have contributed to this written lab report and confirm that all work you have contributed to this lab report is your own work. Any suspicion of copying or plagiarism in this work will result in an investigation of Academic Misconduct and may result in a "0" on the work, an "F" in the course, or possibly more severe penalties, as well as a Disciplinary Notice on your academic record under the Student Code of Academic Conduct, which can be found online at: http://www.ryerson.ca/senate/current/pol60.pdf

1 Objective

The objective of this project is to design and analyze a simple configuration to allow PV panels to connect to an AC grid. As PV panels output a DC voltage, it must be converted to an AC voltage before it can connect with the grid.

2 Design

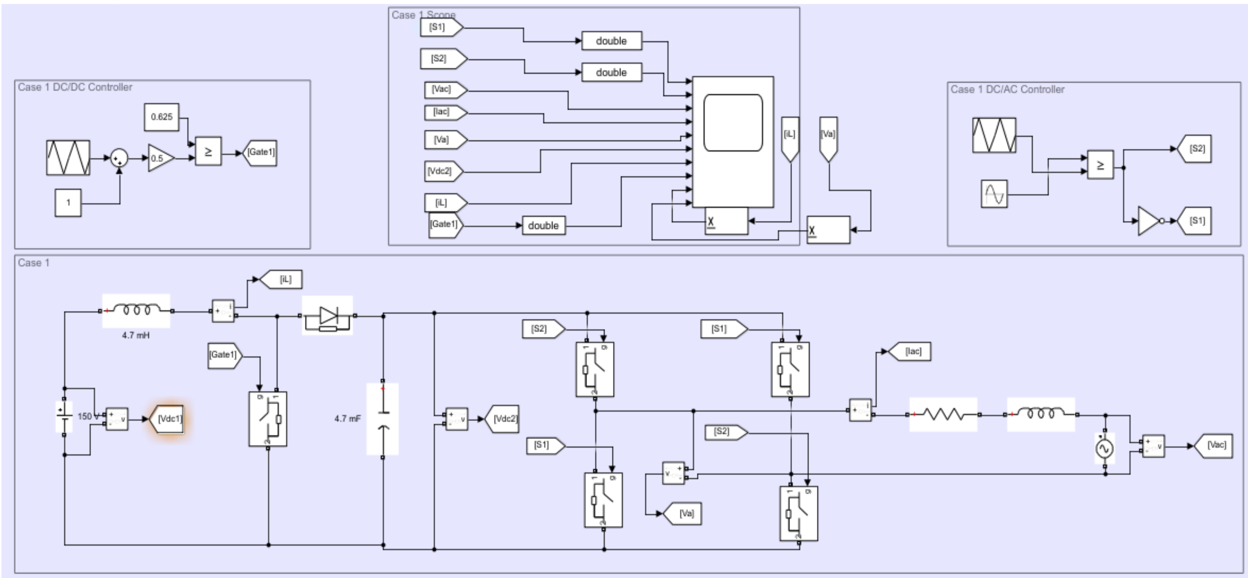


Figure 1: PV Integration System

Figure 1 is the Simulink model for the PV Integration System. The system consists of an initial DC/DC block, which is chosen to be a Boost Converter, and a DC/AC block, chosen to be a Full-Bridge circuit, to supply power to the connected electric grid, simulated here using an AC voltage source.

The system is to operate for 2 separate cases, when $V_{dc1} = 150V$ as well as when $V_{dc1} = 250V$. The voltage input into the DC/AC block will remain a consistent $V_{dc2} = 400V$. Both blocks are controlled using signal of 10kHz. The DC/DC block uses a simple On-Off mechanism whereas the DC/AC block uses a varying On-Off cycle, created using a sine-wave and triangle wave comparator. The DC/AC block creates a PWM waveform as the output.

For case 1, the system is to supply 1.7kW power to the grid. For case 2, the system is to supply 170W to the grid.

3 Simulation Results

Case 1

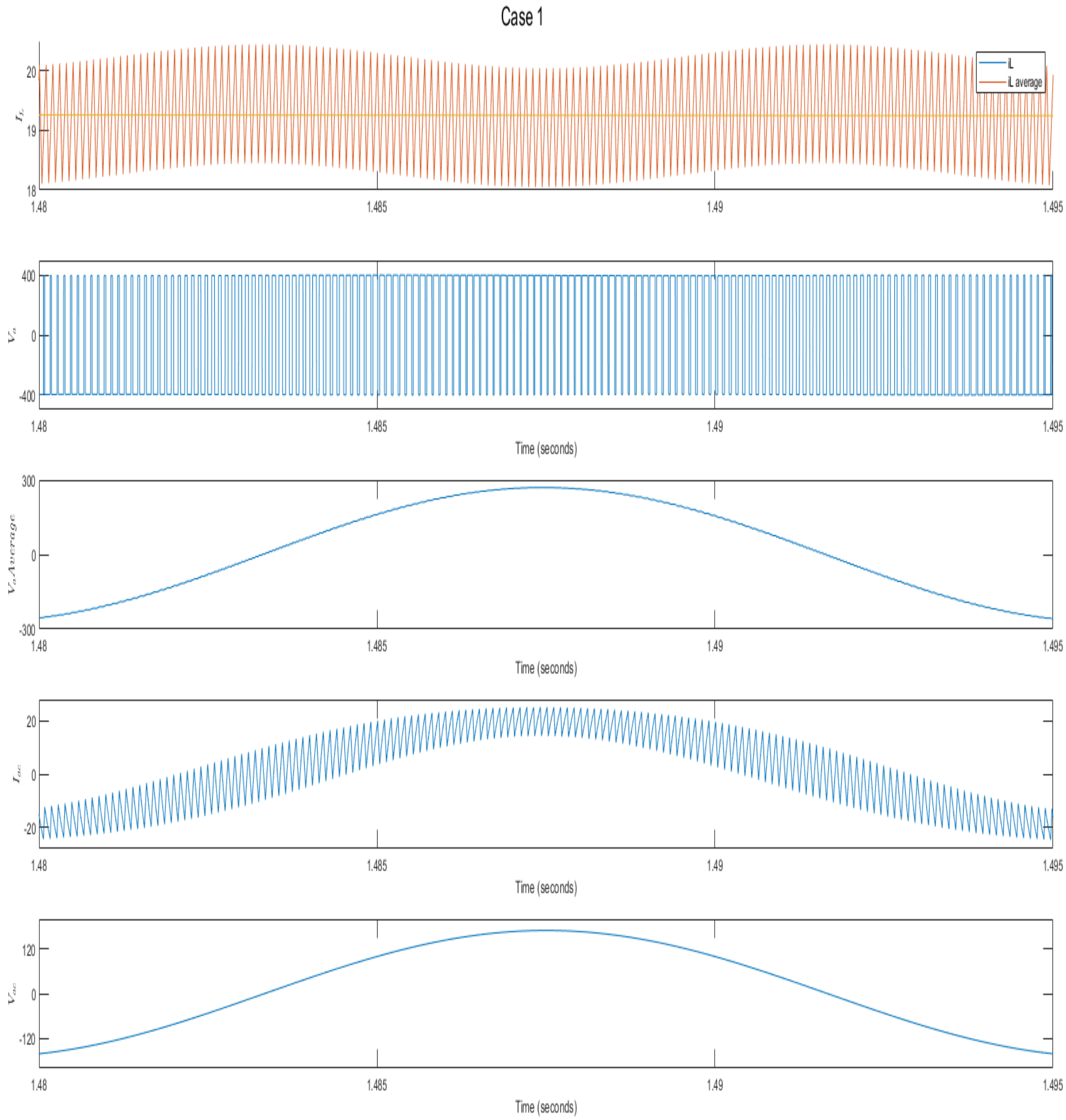


Figure 2: Selected Plots for Case 1

It can be seen that when the PWM output is the thinnest, the value of Iac is at its lowest point. And when the PWM is the widest, the Iac is at its peak. The ripple of the inductor is 2A apart, which is 20% of the fundamental current which is seen in figure 3.

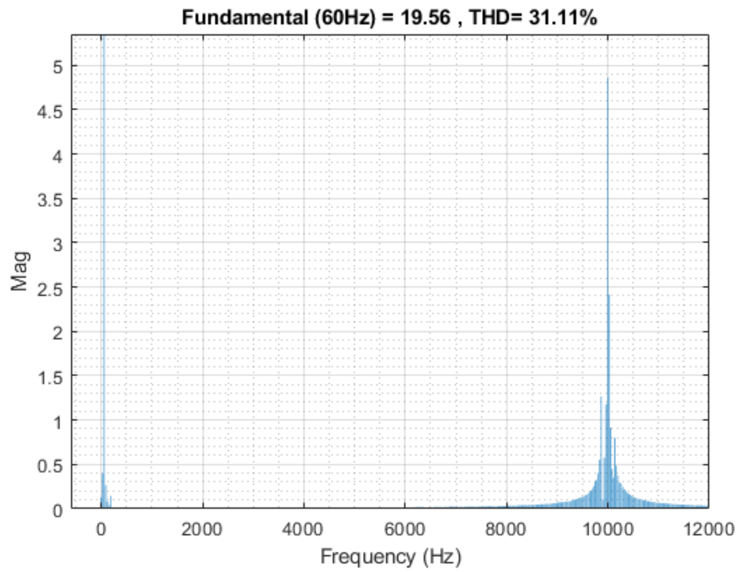


Figure 3: FFT Analysis of Iac

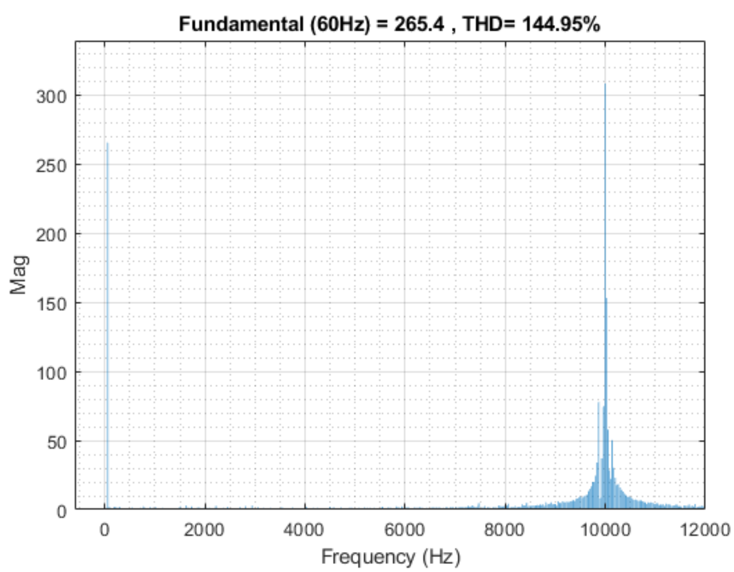


Figure 4: FFT Analysis of Va

The total power supplied by the system at the fundamentals found in figure 3 and 4 is

$$P = \frac{Vdc * Idc}{2}$$

$$= 265.4 * \frac{19.56}{2}$$

$$2595.612W$$

Case 2

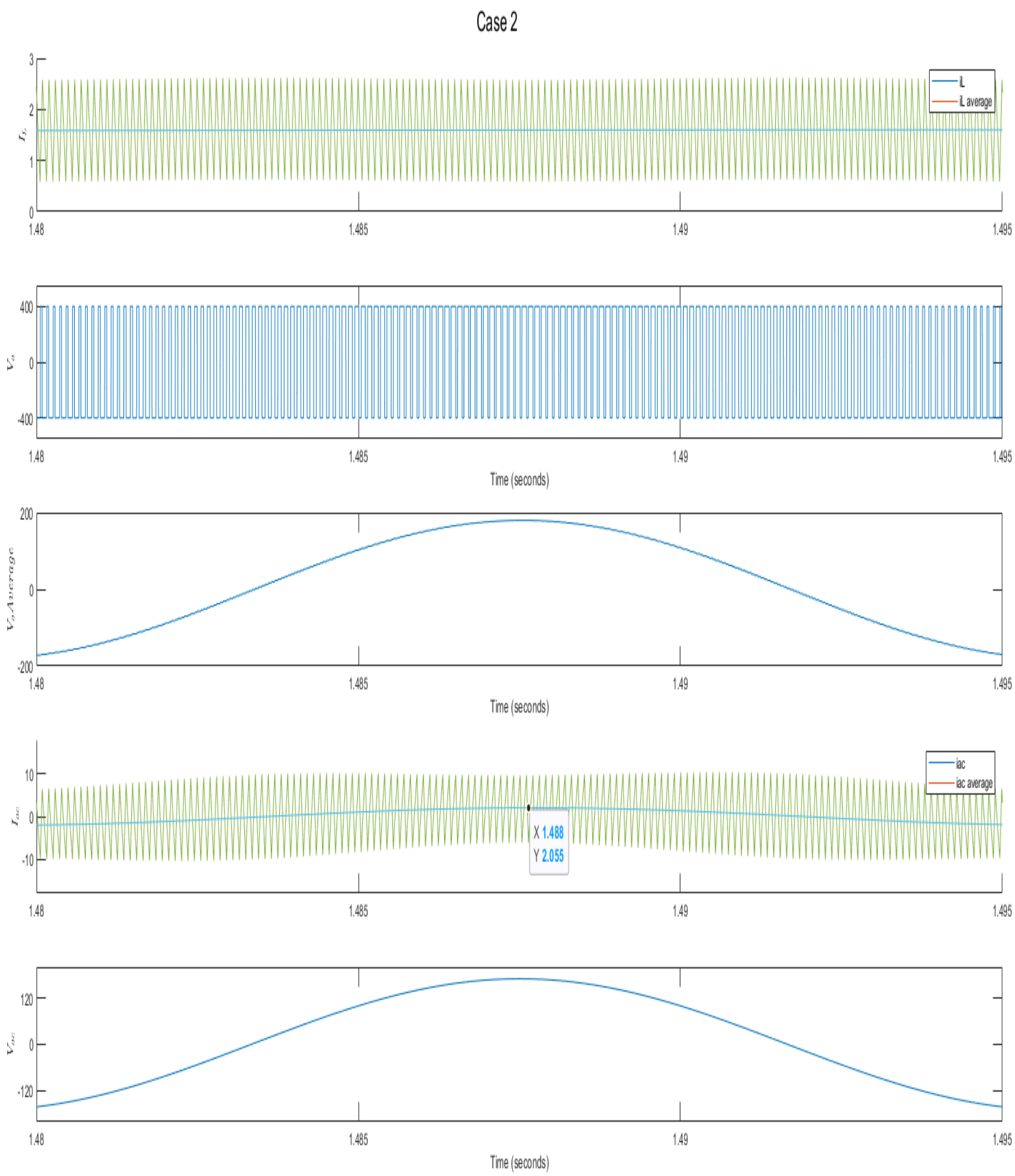


Figure 5: Selected Plots for Case 2

It can be seen that when the PWM output is the thinnest, the value of Iac is at its lowest point. And when the PWM is the widest, the Iac is at its peak. The ripple of the inductor is 2A apart. The average current and voltage has decreased in order to supply less power.

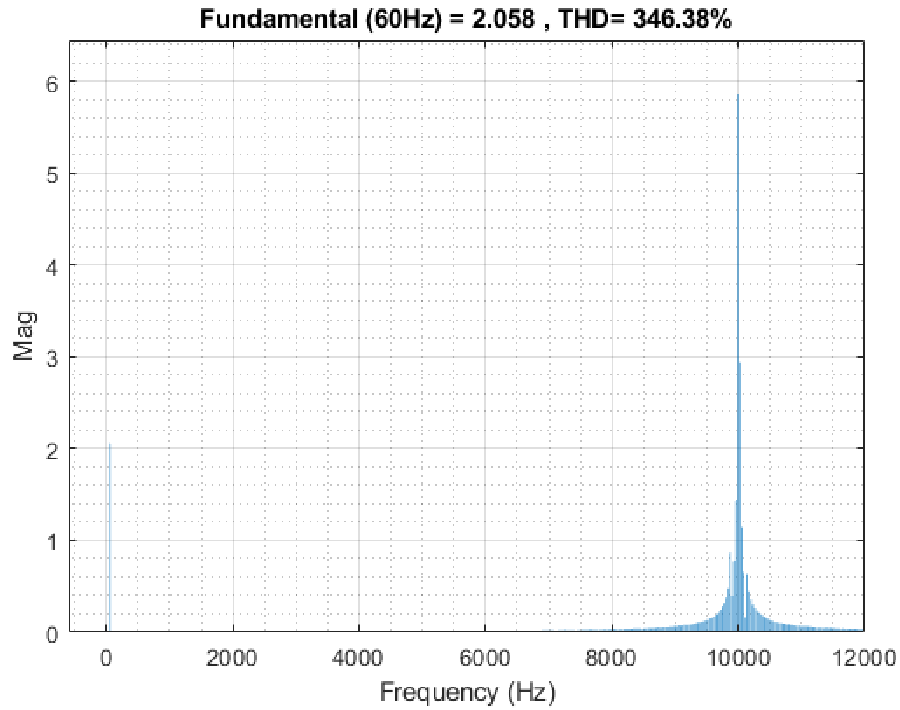


Figure 6: FFT Analysis of Iac

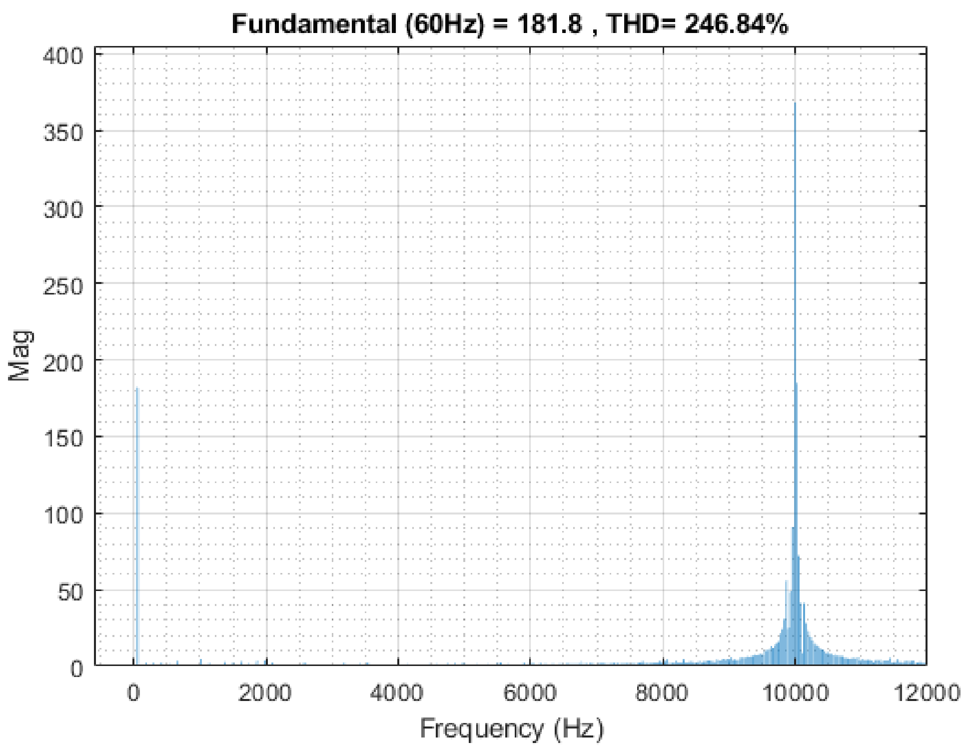


Figure 7: FFT Analysis of Va

4 Conclusion

4.1 Questions

1. Compare the theoretical results of the design to those of the simulation. Do they match? If not, what are some causes for discrepancies?

For case 1, the theoretical results and the simulation matches for the most case. There is a ripple present in the V_{dc2} due to the Boost Converter, as the capacitance value was pre-determined. The Boost converter is operating in CCM. There is also a very tiny, almost negligible ripple on V_a. ΔI_L has a ripple that is 10% of I_{ac}. The current I_{ac} and v_{ac} are in phase with each other.

For case 2, theoretical results does not match entirely as there is a distortion present. The rest match with case 1.

2. Theoretically speaking, what is the difference between the output power, P, of the DC/AC converter and the power, Pac, that is delivered to the grid? Should these two powers be the same? If so, why? If not, why not? Does the simulation agree with what you expect?

The power P is the power taken at the output of the DC/AC converter. It has been assumed that the components in the circuits are lossless, meaning they do not consume any voltage. However, the grid power (Vac) does not consider any power losses due to field impedances (Rf, Lf) in the circuit, so the Pac does not equal to the P.

3. In this project, the system was set to operate in an open-loop manner. That is, multiple parameters were set/changed at a time in order to ensure that the operating conditions of the system were satisfied through the correct parameter values. In practice, such a system would be based on a closed-loop control system that would respond to such changes. Explain how such a closed-loop control can be implemented for this type of system. Which variables would need to be monitored? Which variables would need to be adjusted to ensure that the system operates in the desired manner?

For a closed-loop system, the values that need to be monitored are V_{dc1}, V_{dc2} on the Boost converter. This is because the duty cycle (D) will change according to the changes in these values. Only monitoring V_{dc1}would not be enough as V_{dc2}changing would also result in the need to adjust the duty cycle to ensure that V_{dc2}remains 400V. The only value that will change is the duty cycle.

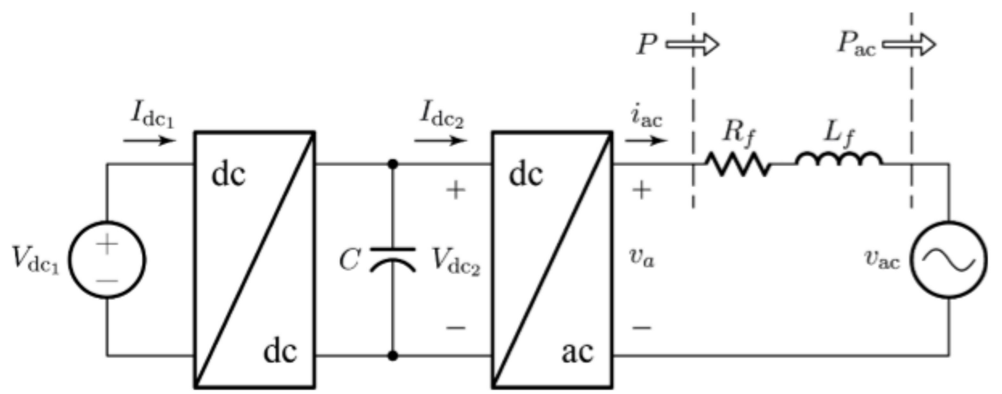
For the DC/AC converter, the values to be monitored are I_{ac} and V_a. This is because these are the only values that will change in order to supply power to the grid. In order to adjust these variables, we need to adjust the modulation index, K, and the phase shift, ∅.

5 Appendix

5.1 Calculations

Prelab

Saturday, November 6, 2021 10:21 PM



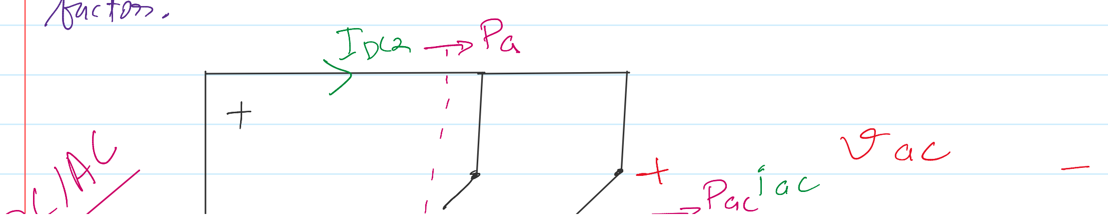
$V_{dc1} = 150V$ & $250V$
$V_{dc2} = 400V$
$v_{ac_{Rms}} = 120V$
$\therefore \hat{v}_{ac} = 120\sqrt{2}\ V$ $\quad f = 60Hz$
$P = 3kW$
$L_f = 1mH$
$R_f = 5\Omega$
$C = 4.7mF$
$f_s = 10kHz$
No Galvanic Isolation
$V_a = \pm V_{dc2}$

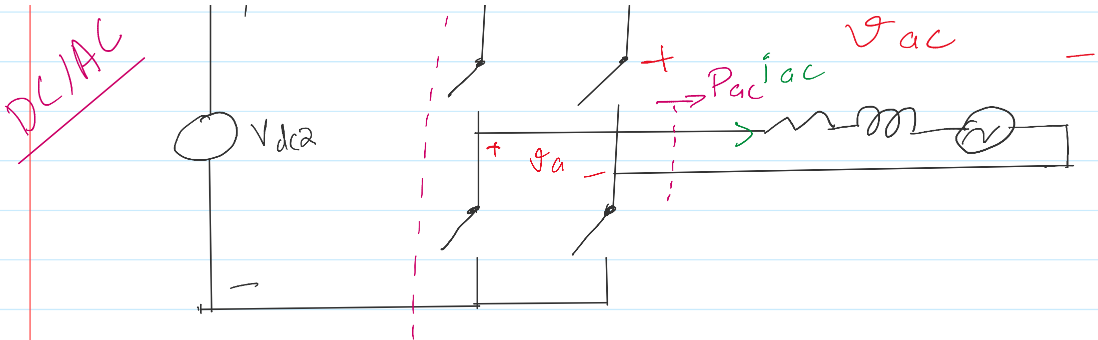
DC/DC is Boost Converter as the voltage V_{dc2} will remain 400V for 150V & 250V

DC/AC is a Full-Bridge Converter as V_a should be from $+V_{dc2}$ to $-V_{dc2}$.
Output will be a 2-level, bipolar PWM waveform.

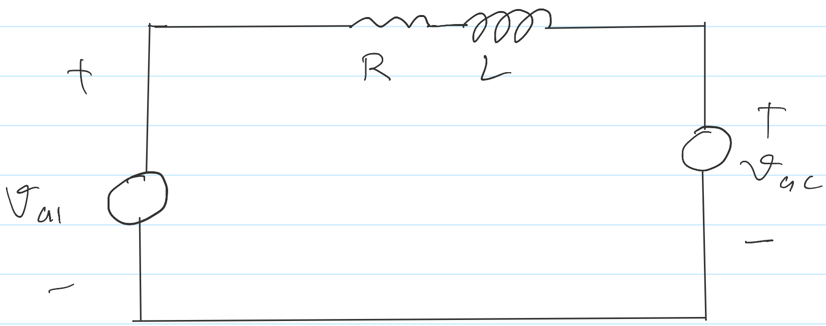
Case 1

Q. Determine k & ϕ when $P_{ac} = 1.7kW$ with unity power factor.





$\delta = 0$ as 2-level.



$$v_{a1} = k\,V_{dc2}$$

$$v_{ac,Rms} = 120\text{ V}$$

$$\hat{v}_{ac} = 120\sqrt{2}\text{ V}$$

$$I_{ac} = \frac{v_{a1} - v_{ac}}{R + j\omega L}$$

$$P = \frac{I_{ac} V_{ac}}{2}\cancel{\cos\theta} = 1.7\text{ kW}$$

1 as unity PF

$$I_{ac} = \frac{1.7\text{ k} \times 2}{V_{ac}} = \frac{1.7\text{ k} \times 2}{120\sqrt{2}}$$

$$= 20.035\text{ A}$$

or 20.04 A

$$20.04\text{ A} = \frac{(kV_{d2})e^{-j\phi} - 120\sqrt{2}}{5 + j(377 \times 10^{-3})}$$

$$(kV_{dc2})e^{-j\phi} = 100.2 + j7.56 + 120\sqrt{2}$$

$$= 269.90 + j7.56$$

$$\therefore \quad kV_{dc22} = \sqrt{269.90^2 + (7.56)^2}$$

$$k = 270.00 \quad = 0.675$$

$$k = \frac{270.00}{400} = 0.6750$$

$$-\phi = \tan^{-1}\left(\frac{7.56}{269.90}\right) = 1.6044$$

$$\therefore \phi = -1.6044^\circ$$

$$\boxed{\begin{aligned} K &= 0.6750 \\ \phi &= 1.6044^\circ \end{aligned}}$$

Q. what percentage of its rated power does the inverter provide?

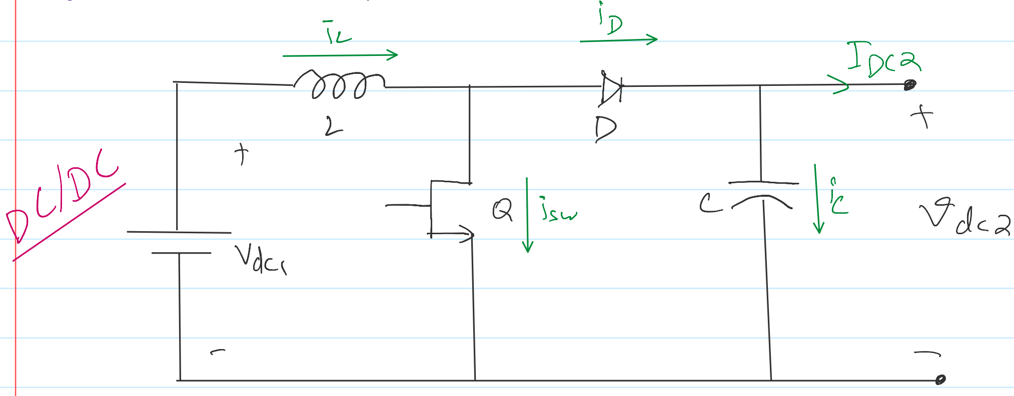
$$P = \frac{V_{dc2} \times I_{dc2}}{2} = K V_{dc2} \times \frac{k V_{dc2} - 120\sqrt{2}}{\sqrt{R^2 + (\omega L)^2}} \times \frac{1}{2}$$

$$= 270 \times \frac{270 - 120\sqrt{2}}{5} \times \frac{1}{2}$$

$$= 2707.95$$

$$\therefore \% \text{ of rated power} = \frac{2707.95}{3000} \times 100 = \boxed{90.265\%}$$

Q. Determine L of the DC/DC converter required to ensure inductor ripple current no larger than 10% of AC-side current's fundamental component.



$V_{dc_1} = 150V$

$V_{dc2} = 400V$

$V_{dc1_{Low}} = 150\ V$ $\quad V_{dc1,high} = 250V$

$\therefore$ when $V_{dc1,low} = 150V$ $\quad D_{MAX} = 1 - \frac{V_{dc1}}{V_{dc2}}$

$= 1 - \frac{150}{400}$

$= 0.625$

when $V_{dc1,high} = 250V$ $\quad D_{MIN} = 1 - \frac{250}{400}$

$= 0.375$

$$\Delta i_L = \frac{V_{dc}}{LF} D_{MAX}$$

$$(0.1)(20.04) = \frac{150}{L \times 10^4}(0.625)$$

$$\boxed{\begin{aligned} L &= 4.67 \times 10^{-3} \\ &= 4.7\ mH \end{aligned}}$$

Q. Conduction Mode

$$I_{OB} = \frac{V_o}{2LF} D(1-D)^2$$

$$= \frac{400}{2 \times 4.7 \times 10^{-3} \times 10^4} 0.625 \times (1 - 0.625)^2$$

$= 0.374\,A$

$$I_{dc_2} = \frac{P}{V_{dc2}} = \frac{2707.94}{400} = 6.7698$$

$\boxed{\text{Operating in CCM}}$

Q. Specify voltage ratings

For the DC/DC converter

The transistor switch will have:

$v_{sw} = v_o$ when switch is off

$\therefore$ 20% safety margin $= v_o \times 1.2 = \boxed{480V \text{ rating}}$

The voltage across the diode will be $-v_o$ when the switch is off:

$v_d = -v_o$

$\therefore$ 20% safety margin $= v_d \times 1.2 = \boxed{480V \text{ rating}}$

For worst case, limiting factor is D:

$D = 0.625$

$I_{oB} = \frac{TV_o}{2L} D(1-D)^2 = \frac{TV_o}{2L}(0.0878)$

$D = 0.375$

$I_{oB} = \frac{TV_o}{2L} D(1-D)^2 = 0.1464$

$\therefore$ When $D = 0.625$, that is the worst case

$$I_{oB} = \frac{V_o}{2LF}(0.0878) = \frac{400}{2\times 4.7\times 10^{-3}\times 10^{4}}(0.0878) = 0.3736\,A$$

$\therefore$ $\boxed{20\% \text{ safety} = 0.3736 = 0.448A \text{ or } 0.5A}$

Case 2

Q. If $V_{dc1} = 250V$, determine the duty cycle required to operate in the same manner as Case 1.

$V_{dc1} = 250V \qquad V_{dc2} = 400V$

$$\therefore \quad D = 1 - \frac{250}{400} = 0.375$$

Q. Determine conduction mode of the DC/DC converter.

$$I_{oB} = \frac{V_o}{2LF} D(1-D)^2$$

$$= \frac{400}{2 \times 4.7 \times 10^{-3} \times 10^4} (0.375)(1-0.375)^2$$

$$= 4.255 \times 0.1464$$

$$= 0.623 A$$

$$I_{dc2} = \frac{2.7698k}{400} = 6.9245 A$$

So operating in $\boxed{CCM}$

Q. Calculate the modulation index and magnitude of the fundamental components v_a and i_{ac} if P_{ac} is 10% of the value of Case 1.

$$10\% \times P_{ac} = 1.7k \times 10\% = 170V$$

$$P = \frac{I_{ac} V_{ac}}{2} = 170V$$

$$I_{ac} = 2A$$

$$I_{ac} = \frac{v_{a1} - V_{ac}}{R + j\omega L} = 2$$

$$\Rightarrow 2(R + j\omega L) + V_{ac} = v_{a1}$$

$$(kV_{dc2}) e^{-j\Phi} = 179.705 + j\,0.754$$

$$\therefore \quad kV_{dc2} = \sqrt{179.705^2 + 0.754^2}$$

$$K = \frac{179.70}{V_{dc2}}$$

$$= 0.45$$

$$-\phi = \tan^{-1}\left(\frac{0.754}{179.705}\right)$$

$$= 0.2403$$

$$\therefore \phi = -0.2403$$

$$\therefore \boxed{\begin{aligned} K &= 0.45 \\ \phi &= -0.2403 \end{aligned}}$$

$$\therefore v_{a_1} = kV_{dc2} = 180V$$

$$i_{ac} = \frac{kV_{dc2} - 120\sqrt{2}}{\sqrt{R^2 + \omega L^2}} = 2.06A$$

$$\therefore \boxed{\begin{aligned} v_a &= 180V \\ i_{ac} &= 2.06A \end{aligned}}$$

Q. What % of its rated power does the inverter provide?

$$\therefore \quad P = \frac{V_{dc2} \times I_{dc2}}{2}$$

$$= \frac{1}{2} \times (180)\left(\frac{180 - \hat{V}_{ac}}{\sqrt{R^2 + \omega L^2}}\right)$$

$$= \frac{1}{2} \times 180 \times 2$$

$$= 180\ W$$

$$\therefore \quad \%\ \text{rated power} = \frac{180}{3000} \times 100 = \boxed{6\ \%}$$