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

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Instructor:	Sandeep Kaler

Assignment/Lab Number:	Lab 3
Assignment/Lab Title:	DC/AC Converters

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*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 lab is to analyze, simulate and investigate the functionality and properties of an AC/AC conversion system based on AC/DC and DC/AC converters. The THD of v_{ac} and i_{ac}, the peak grid voltage v_g and V_{dc} were studied.

2. Design and Implementation

2.1 AC/AC Converters

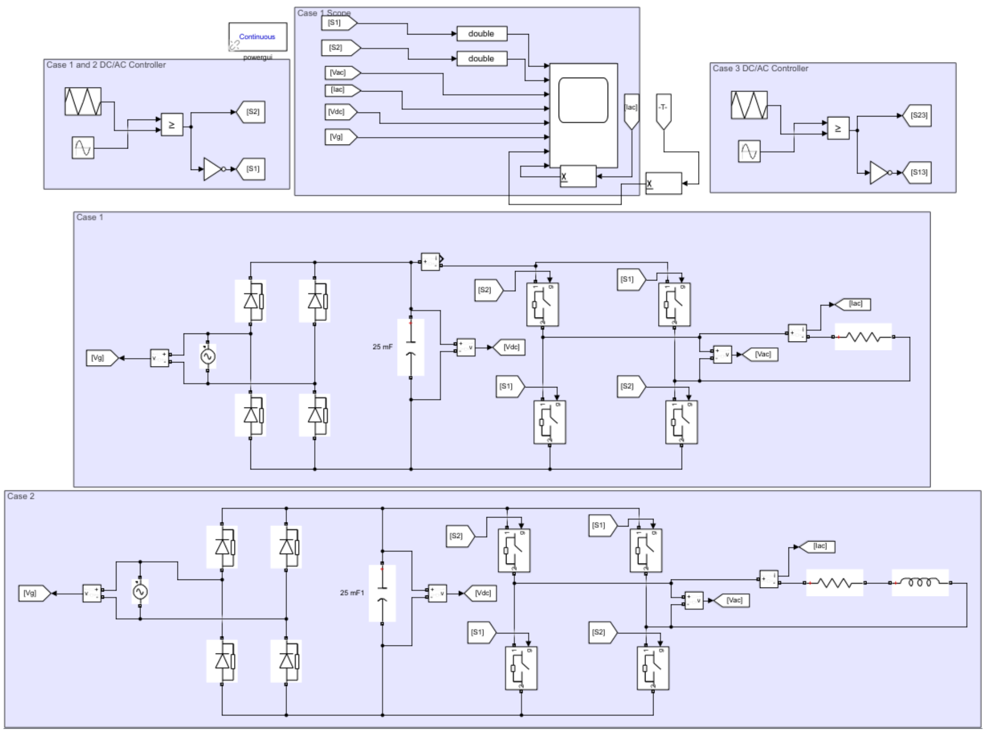


Figure 1: AC/AC Converters for Case 1 and 2

Figure 1 is the Simulink model for the AC/AC converter. It consists of an AC/DC block on the left half, connecting the “grid voltage”, and a DC/AC block on the right, to generate a PWM voltage waveform as the output.

The system was studied for 2 cases. The first case was just a resistive load. The second and third case added an inductor, creating an inductive load.

3. Experimental Results

3.1 Case 1

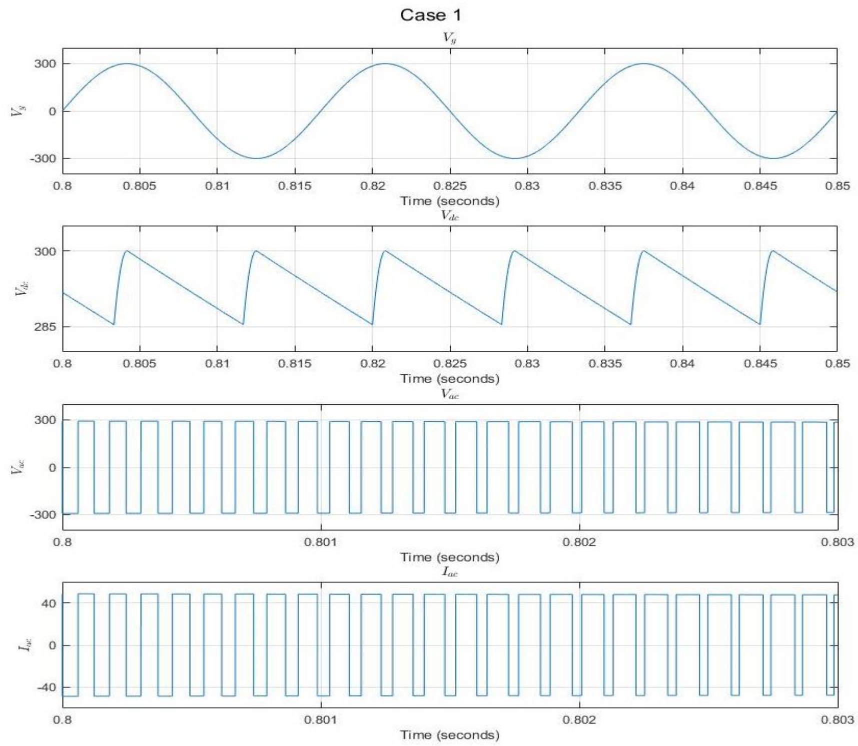


Figure 2: Case 1 Waveforms

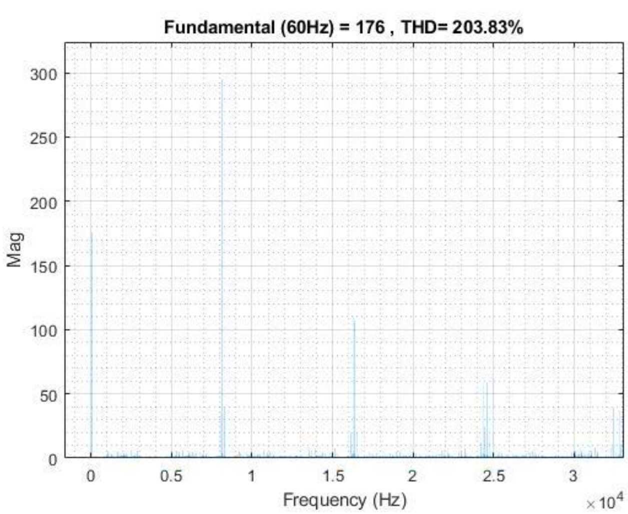


Figure 3: FFT Analysis of Vac

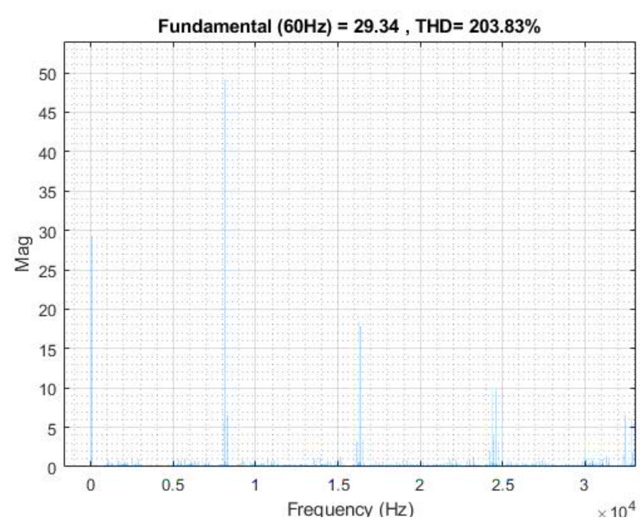


Figure 4: FFT Analysis of Iac

The **fundamental value** of Vac was calculated as 127.8V RMS, or 180.73V magnitude. This is very close to what was found using FFT, 176V. Similarly, the current Iac was calculated to 21.213A RMS, or 29.99A magnitude. This is very close to the FFT analysis value of 29.34A.

Similar to the magnitudes, the **THD**s are also very close to the calculated values, with THD of V calculated as 201.4% and THD of A calculated as 201.43% and the simulation generating THD 203.83% for V and 203.83% for A.

3.2 Case 2

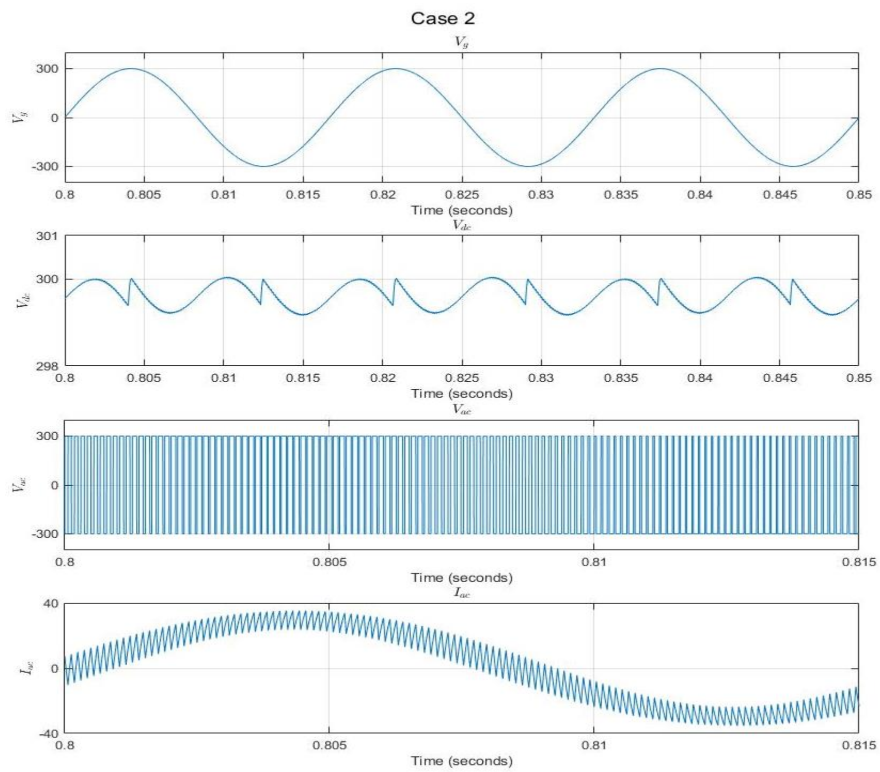


Figure 5: Case 2 Waveforms

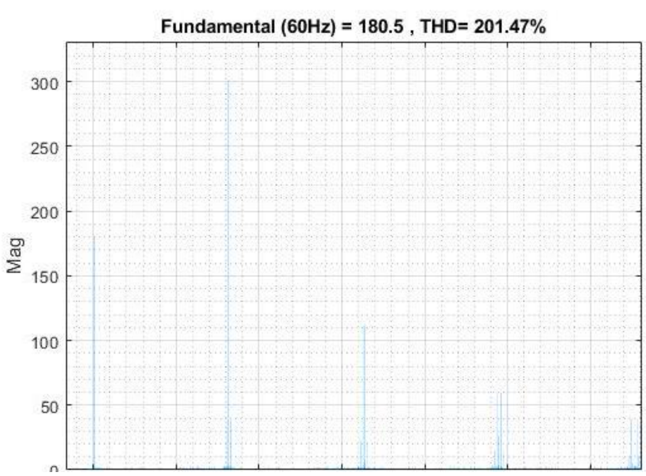


Figure 6: FFT Analysis of V

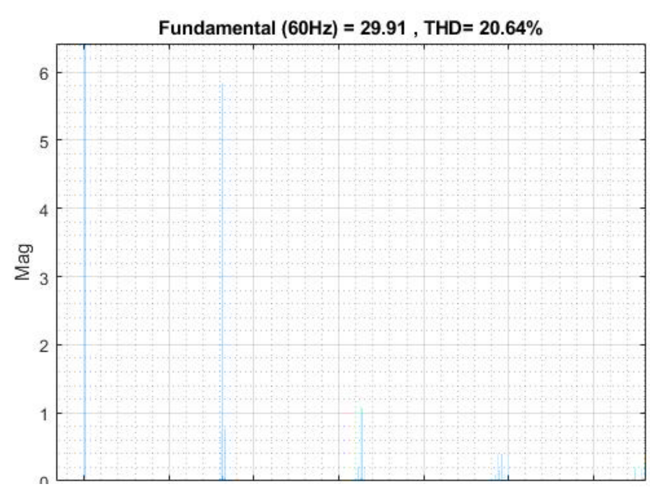


Figure 7: FFT Analysis of I

The **fundamental value** of Vac was calculated as 127.8V RMS, or 180.73V magnitude. This is very close to what was found using FFT, 180.5V. Similarly, the current Iac was calculated to 21.213A RMS, or 29.99A magnitude. This is very close to the FFT analysis value of 29.91A.

Similar to the magnitudes, the **THD**s are also very close to the calculated values, with THD of V calculated as 201.4% and THD of A calculated as 20.60% and the simulation generating THD 201.47% for V and 20.64% for A.

3.3 Case 3

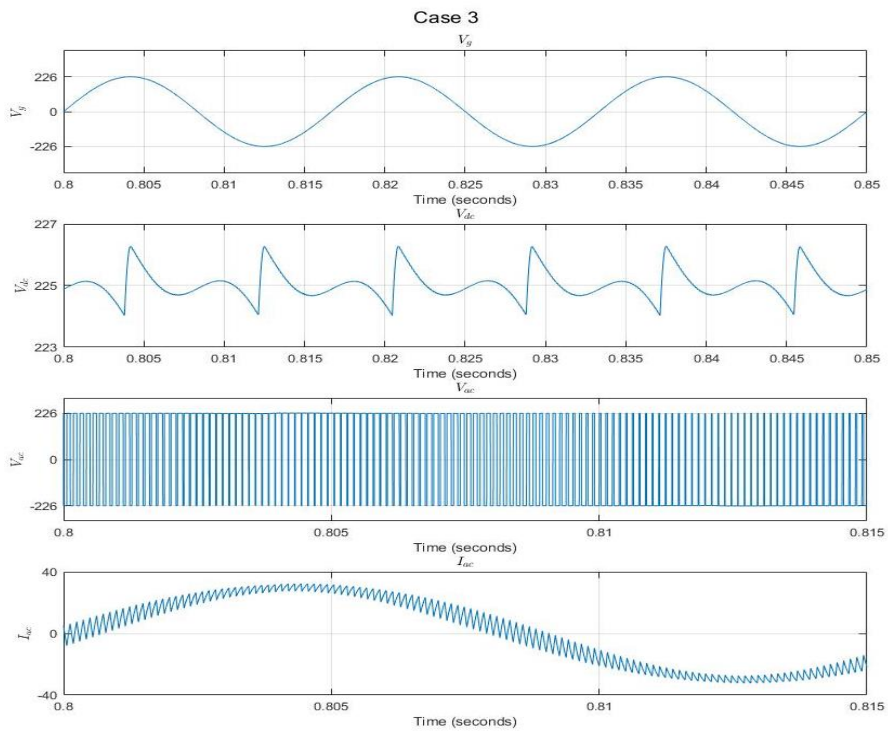


Figure 8: Case 3 Waveform

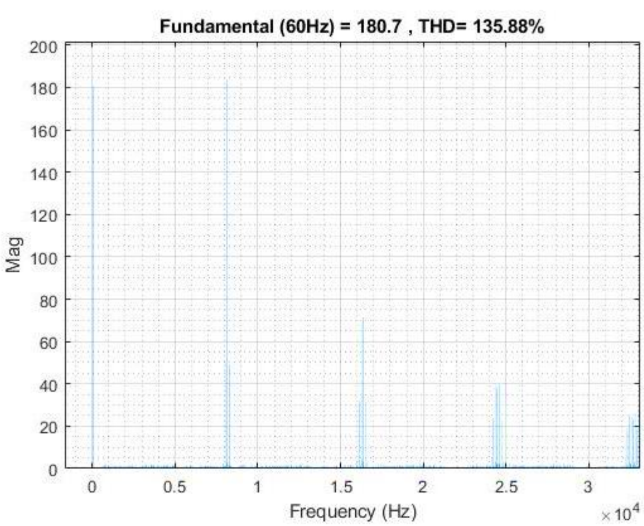


Figure 9: FFT Analysis of V

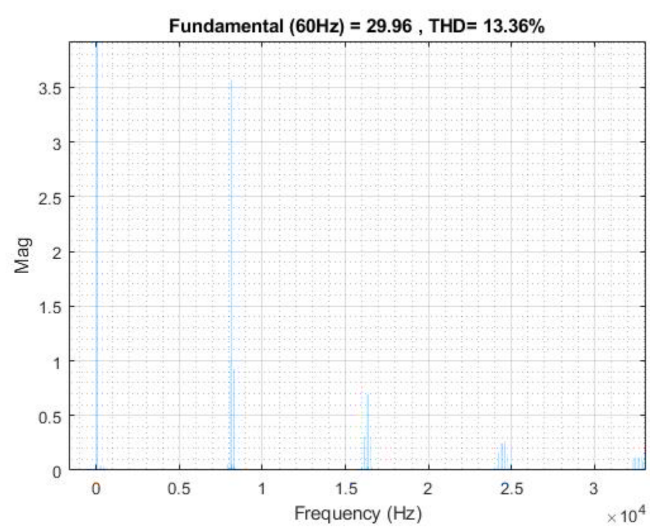


Figure 10: FFT Analysis of I

The **fundamental value** of Vac was calculated as 127.8V RMS, or 180.73V magnitude. This is very close to what was found using FFT, 180.7V. Similarly, the current Iac was calculated to 21.213A RMS, or 29.99A magnitude. This is very close to the FFT analysis value of 29.96A.

Similar to the magnitudes, the **THD**s are also very close to the calculated values, with THD of V calculated as 135.7% and THD of A calculated as 12.68% and the simulation generating THD 135.88% for V and 13.36% for A.

4. Conclusion

4.1 Post-Lab

1. **Compare the theoretical results of the prelab to those of the simulation. Do they match? If not, what are some causes for discrepancies?**
   Comparing the theoretical and the prelab calculations, both results are very similar if not exactly the same. The small discrepancies present could be due to rounding error as well as the very small voltage drops of the diodes as well as very small resistances of the semiconductor components. The numerical comparisons are under each graphs above.

2. **Consider Case 1 and Case 2. What is the main difference between these two cases? What is responsible for this difference? How would the harmonic performance of these two cases change if the switching frequency were reduced?**
   The main difference between the two cases is the presence of the inductor. This changes the behaviour, as the addition of the inductor smoothens the current output, as well reduces power loss, by reducing the distortions presence from the harmonic components.

3. **Calculate the amount of power lost to distortion harmonics for both Case 1 and Case 2**
   Case 1:
   $$Power_{Real} = \frac{{I_{Distortion}}^2}{2} * R = \frac{(42.73\sqrt{2})^2}{2} * 6 = 10955W = 109.55kW$$
   As case 1 does not contain any inductive component, there is no reactive component to the power.
   Case 2:
   $$Power_{Real} = \frac{{I_{Distortion}}^2}{2} * R = \frac{(4.37\sqrt{2})^2}{2} * 6 = 114.6W$$
   $$Power_{Reactive} = \frac{{I_{Distortion}}^2}{2} * jwl = 1065.611Var$$
   In order to calculate $Power_{Reactive}$, the same approach as Case 1 could not be used as the inductive impedance changes along the harmonics. In order to accomplish this, the I_{RMS} values that were calculated was squared, then multiplied by their respective impedance values before adding them together.

$$Power_{Reactive} = \sum_{n=2}^{\infty} \frac{(I_{Distortion,Peak})^2 * jwl}{2}$$

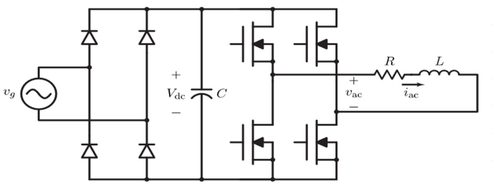
Overall, case 2 has significantly lower power loss than case 1.

5. Appendix

5.1 Prelab

Prelab

November 8, 2021 1:17 PM



2.1 - Case 1

Assume that the full-bridge inverter operates under a bipolar PWM scheme and that the grid frequency is 60 Hz. Considering the harmonics shown in Figure 2 (on Page 3), if $V_{dc} = 300V, f = 60Hz, f_{sw} = 8160Hz, R = 6\Omega, L = 0$, and the fundamental ac-side voltage of the dc/ac converter has a peak magnitude of $180V$, determine:

- The THD of v_{ac} and i_{ac}
- The peak grid voltage, v_g

Note, for this analysis, you may assume that V_{dc} is a constant, ripple-free voltage and that C is large.

$V_{dc} = 300V \quad R = 6\Omega \quad L = 0\,mH$

$f = 60Hz \quad f_{sw} = 8160Hz \quad \hat{v}_{ac} = 180V$

$m_f = \frac{8160}{60} = 136 \quad K = \frac{\hat{V}_{ac}}{V_{dc}} = \frac{180}{300} = 0.6$

THD of Vac

Fundamental

$h=1, V_{01} \Rightarrow v_{ac_1} = \frac{K\,V_{dc}}{\sqrt{2}} = \frac{0.6\times300}{\sqrt{2}} = \boxed{127.28\,V_{RMS}}$

$m_f = V_{ac_{136}} = \frac{(1.006)(300)}{\sqrt{2}} = 213.40\ V_{RMS}$

$m_f\pm2 = V_{ac_{134/138}} = \frac{(0.131)(300)}{\sqrt{2}} = 27.79\ V_{RMS}$

$2m_f\pm1 = V_{ac_{271,273}} = \frac{(0.370)(300)}{\sqrt{2}} = 78.48\,V_{RMS}$

$2m_f\pm3 = V_{ac_{269,275}} = \frac{(0.071)(300)}{\sqrt{2}} = 15.06\ V_{RMS}$

$3m_f = V_{ac_{408}} = \frac{(0.083)(300)}{\sqrt{2}} = 17.60\,V_{RMS}$

$3m_f\pm2 = V_{ac_{406,410}} = \frac{(0.203)(300)}{\sqrt{2}} = 43.06\,V_{RMS}$

$3m_f\pm4 = V_{ac_{404,412}} = \frac{(0.047)(300)}{\sqrt{2}} = 9.97\,V_{RMS}$

$4m_f\pm1 = V_{ac_{543,545}} = \frac{(0.008)(300)}{\sqrt{2}} = 1.69\ V_{RMS}$

$4m_f\pm3 = V_{ac_{541,547}} = \frac{(0.132)(300)}{\sqrt{2}} = 28\ V_{RMS}$

$4m_f\pm5 = V_{ac_{539,549}} = \frac{(0.034)(300)}{\sqrt{2}} = 7.212\ V_{RMS}$

$$\text{RMS distortion} = \sqrt{213.4^2 + 2(27.79)^2 + 2(78.48)^2 + 2(15.06)^2 + 17.60^2 + 2(43.06)^2 + 2(9.97)^2 + 2(1.69)^2 + 2(28)^2 + 2(7.212)^2}$$

$= 256.42$

$\therefore \text{THD of } V = \frac{256.42}{127.28}\times100 = \boxed{201.4\,\%}$

Peak grid voltage, Vg

$V_{ac} = 300V \quad f = 60Hz$

$\therefore V_g = 300\sin(377t)$

The presence of the DC-link capacitor smoothens the output, resulting in $V_{DC} \approx v_{g\,peak}$

$\therefore$ Peak grid voltage $= \boxed{300V}$

THD of iac

Fundamental

$I_{ac,RMS} = \frac{180}{\sqrt{2}\times6} = \boxed{21.213\,A_{RMS}}$

$h=1, i_{01} \Rightarrow i_{ac_1} = \frac{v_{ac}}{\sqrt{2}\times6} = \frac{180.00}{\sqrt{2}\times6} = 21.213\ A_{RMS}$

$m_f = i_{ac_{136}} = \frac{301.9}{\sqrt{2}\times6} = 35.567\ A_{RMS}$

$m_f\pm2 = i_{ac_{134/138}} = \frac{39.30}{\sqrt{2}\times6} = 4.63\ A_{RMS}$

$2m_f\pm1 = i_{ac_{271,273}} = \frac{110.98}{\sqrt{2}\times6} = 13.08\ A_{RMS}$

$2m_f\pm3 = i_{ac_{269,275}} = \frac{21.29}{\sqrt{2}\times6} = 2.51\ A_{RMS}$

$3m_f = i_{ac_{408}} = \frac{24.89}{\sqrt{2}\times6} = 2.93\ A_{RMS}$

$3m_f\pm2 = i_{ac_{406,410}} = \frac{60.89}{\sqrt{2}\times6} = 7.176\ A_{RMS}$

$3m_f\pm4 = i_{ac_{404,412}} = \frac{14.09}{\sqrt{2}\times6} = 1.66\ A_{RMS}$

$4m_f\pm1 = i_{ac_{543,545}} = \frac{2.39}{\sqrt{2}\times6} = 0.281\ A_{RMS}$

$4m_f\pm3 = i_{ac_{541,547}} = \frac{39.59}{\sqrt{2}\times6} = 4.67\ A_{RMS}$

$4m_f\pm5 = i_{ac_{539,549}} = \frac{10.19}{\sqrt{2}\times6} = 1.202\ A_{RMS}$

$$\text{RMS distortion} = \sqrt{35.56^2 + 2(4.63)^2 + 2(13.08)^2 + 2(2.51)^2 + 2.93^2 + 2(7.17)^2 + 2(1.67)^2 + 2(0.28)^2 + 2(4.67)^2 + 2(1.202)^2}$$

$= 42.73\,A$

$\therefore \text{THD} = \frac{42.73}{21.213}\times100 = \boxed{201.43\,\%}$

2.2 – Case 2

Repeat the process of Case 1 if $L = 1mH$.

THD of Vac

Fundamental

$h=1, V_{01} \Rightarrow v_{ac_1} = \frac{K\,V_{dc}}{\sqrt{2}} = \frac{0.6\times300}{\sqrt{2}} = \boxed{127.28\,V_{RMS}}$

$m_f = V_{ac_{136}} = \frac{(1.006)(300)}{\sqrt{2}} = 213.40\ V_{RMS}$

$m_f\pm2 = V_{ac_{134/138}} = \frac{(0.131)(300)}{\sqrt{2}} = 27.79\ V_{RMS}$

$2m_f\pm1 = V_{ac\ldots} = (0.370)(300) = 78.48\,V_{RMS}$

THD of iac

Fundamental

$I_{ac,RMS} = \frac{180}{\sqrt{2}\times6} = \boxed{21.213\,A_{RMS}}$

$h=1, i_{01} \Rightarrow i_{ac_1} = \frac{v_{ac}}{\sqrt{2}\times6} = \frac{180.00}{\sqrt{2}\times6 + j0.377} = 21.213\ A_{RMS}$

$m_f = i_{ac_{136}} = \frac{301.9}{\sqrt{2}\times6 + j(2\pi\times60\times136\times1\times0.001)} = 4.134\ A_{RMS}$

$\ldots\ 39.30 \ldots = 0.538\ A_{RMS}$

$$mf\pm2 = V_{ac_{134,138}} = \frac{(0.131)(300)}{\sqrt{2}} = 27.79\ V_{RMS}$$

$$2mf\pm1 = V_{ac_{271,273}} = \frac{(0.370)(300)}{\sqrt{2}} = 78.48\ V_{RMS}$$

$$2mf\pm3 = V_{ac_{269,275}} = \frac{(0.071)(300)}{\sqrt{2}} = 15.06\ V_{RMS}$$

$$3mf = V_{ac_{408}} = \frac{(0.083)(300)}{\sqrt{2}} = 17.60\ V_{RMS}$$

$$3mf\pm2 = V_{ac_{406,410}} = \frac{(0.203)(300)}{\sqrt{2}} = 43.06\ V_{RMS}$$

$$3mf\pm4 = V_{ac_{404,412}} = \frac{(0.047)(300)}{\sqrt{2}} = 9.97\ V_{RMS}$$

$$4mf\pm1 = V_{ac_{543,545}} = \frac{(0.008)(300)}{\sqrt{2}} = 1.69\ V_{RMS}$$

$$4mf\pm3 = V_{ac_{541,547}} = \frac{(0.132)(300)}{\sqrt{2}} = 28\ V_{RMS}$$

$$4mf\pm5 = V_{ac_{539,549}} = \frac{(0.034)(300)}{\sqrt{2}} = 7.212\ V_{RMS}$$

$$\text{RMS distortion} = \sqrt{213.4^2 + 2(27.79)^2 + 2(78.48)^2 + 2(15.06)^2 + 17.60^2 + 2(43.06)^2 + 2(9.97)^2 + 2(1.69)^2 + 2(28)^2 + 2(7.212)^2}$$

$$= 256.42$$

$$\therefore \text{THD of } V = \frac{256.42}{127.28} \times 100 = \boxed{201.4\ \%}$$

$$mf = i_{ac_{136}} = \frac{301.9}{\sqrt{2}\times 6 + j(2\pi\times 60\times 136\times 1\times 0.001)} = 4.134\ A_{RMS}$$

$$mf\pm2 = i_{ac_{134,138}} = \frac{39.30}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 1\times 0.001)} = 0.538\ A_{RMS}$$

$$2mf\pm1 = i_{ac_{271,273}} = \frac{110.98}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 2\times 0.001)} = 0.764\ A_{RMS}$$

$$2mf\pm3 = i_{ac_{269,275}} = \frac{21.29}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 2\times 0.001)} = 0.146\ A_{RMS}$$

$$3mf = i_{ac_{408}} = \frac{24.89}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 3\times 0.001)} = 0.114\ A_{RMS}$$

$$3mf\pm2 = i_{ac_{406,410}} = \frac{60.89}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 3\times 0.001)} = 0.279\ A_{RMS}$$

$$3mf\pm4 = i_{ac_{404,412}} = \frac{14.09}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 3\times 0.001)} = 0.064\ A_{RMS}$$

$$4mf\pm1 = i_{ac_{543,545}} = \frac{2.39}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 4\times 0.001)} = 0.008\ A_{RMS}$$

$$4mf\pm3 = i_{ac_{541,547}} = \frac{39.59}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 4\times 0.001)} = 0.136\ A_{RMS}$$

$$4mf\pm5 = i_{ac_{539,549}} = \frac{10.19}{\sqrt{2}\times 6\times j(2\pi\times 60\times 136\times 4\times 0.001)} = 0.035\ A_{RMS}$$

$$\text{RMS distortion} = \sqrt{4.13^2 + 2(0.538)^2 + 2(0.764)^2 + 2(0.146)^2 + 0.114^2 + 2(0.279)^2 + 2(0.064)^2 + 2(0.008)^2 + 2(0.136)^2 + 2(0.035)^2}$$

$$= 4.37$$

$$\therefore \text{THD} = \frac{4.37}{21.213} \times 100 = \boxed{20.60\ \%}$$

Peak grid voltage, V_g

$V_{ac} = 300V \quad f = 60\ Hz$

$\therefore V_g = 300 \sin(377t)$

$\therefore$ Peak grid voltage $= \boxed{300V}$

The addition of an inductor on the load doesn't impact V_{dc}, so the peak V_g doesn't change

2.3 – Case 3

If the fundamental component of the ac-side voltage should maintain the same value as the previous two cases, while the RMS value of the grid voltage is 160V, calculate the dc-link voltage, V_{dc}. Then, determine the THD of v_{ac} and i_{ac}.

Grid Voltage

$V_{g,RMS} = 160V$

As $V_{g,peak} \approx V_{dc}$

$V_{dc} = \sqrt{2} \times 160V = \boxed{226.27V}$

$\hat{V}_{ac} = 180V$

$\therefore k = \frac{180}{226.27} = 0.7955$

For simplicity, and to use the table, consider $k = 0.8$

THD of V_{ac}

Fundamental

$$h=1, V_{o1} \Rightarrow V_{ac_1} = \frac{k V_{dc}}{\sqrt{2}} = \frac{0.8\times 226.27}{\sqrt{2}} = \boxed{127.99 V_{RMS}}$$

$$mf = V_{ac_{136}} = \frac{0.818\times 226.27}{\sqrt{2}} = 130.87\ V_{RMS}$$

$$mf\pm2 = V_{ac_{134,138}} = \frac{0.22\times 226.27}{\sqrt{2}} = 35.19\ V_{RMS}$$

$$2mf\pm1 = V_{ac_{271,273}} = \frac{0.314\times 226.27}{\sqrt{2}} = 50.24\ V_{RMS}$$

$$2mf\pm3 = V_{ac_{269,275}} = \frac{0.139\times 226.27}{\sqrt{2}} = 22.24\ V_{RMS}$$

$$2mf\pm5 = V_{ac_{267,277}} = \frac{0.013\times 226.27}{\sqrt{2}} = 2.08\ V_{RMS}$$

$$3mf = V_{ac_{408}} = \frac{0.171\times 226.27}{\sqrt{2}} = 27.36\ V_{RMS}$$

$$3mf\pm2 = V_{ac_{406,410}} = \frac{0.176\times 226.27}{\sqrt{2}} = 28.16\ V_{RMS}$$

$$3mf\pm4 = V_{ac_{404,412}} = \frac{0.104\times 226.27}{\sqrt{2}} = 16.64\ V_{RMS}$$

THD of i_{ac}

Fundamental

$$h=1, i_{o1} \Rightarrow i_{ac_1} = \frac{V_{ac_1}}{R+j\omega L} = \frac{127.99}{6+j(0.377)} = \boxed{21.29 A_{RMS}}$$

$$mf = i_{ac_{136}} = \frac{V_{ac_{136}}}{R+j\omega L} = \frac{130.87}{6+j(60\times 136\times 1\times 2\pi\times 0.001)} = 2.53\ A_{RMS}$$

$$mf\pm2 = i_{ac_{134,138}} = \frac{V_{ac_{134,138}}}{R+j\omega L} = \frac{35.19}{6+j(60\times 136\times 1\times 2\pi\times 0.001)} = 0.342\ A_{RMS}$$

$$2mf\pm1 = i_{ac_{271,273}} = \frac{V_{ac_{271,273}}}{R+j\omega L} = \frac{50.24}{6+j(60\times 136\times 2\times 2\pi\times 0.001)} = 0.489\ A_{RMS}$$

$$2mf\pm3 = i_{ac_{269,275}} = \frac{V_{ac_{269,275}}}{R+j\omega L} = \frac{22.24}{6+j(60\times 136\times 2\times 2\pi\times 0.001)} = 0.216\ A_{RMS}$$

$$2mf\pm5 = i_{ac_{267,277}} = \frac{V_{ac_{267,277}}}{R+j\omega L} = \frac{2.08}{6+j(60\times 136\times 2\times 2\pi\times 0.001)} = 0.0202\ A_{RMS}$$

$$3mf = i_{ac_{408}} = \frac{V_{ac_{408}}}{R+j\omega L} = \frac{27.36}{6+j(60\times 136\times 3\times 2\pi\times 0.001)} = 0.53\ A_{RMS}$$

$$3mf\pm2 = i_{ac_{406,410}} = \frac{V_{ac_{406,410}}}{R+j\omega L} = \frac{28.16}{6+j(60\times 136\times 3\times 2\pi\times 0.001)} = 0.274\ A_{RMS}$$

$$3mf\pm4 = i_{ac_{404,412}} = \frac{V_{ac_{404,412}}}{R+j\omega L} = \frac{16.64}{6+j(60\times 136\times 3\times 2\pi\times 0.001)} = 0.161\ A_{RMS}$$

$3m_f \pm 2 = V_{ac\,406,410} = \frac{\ldots}{\sqrt{2}} = \ldots V_{RMS}$

$3m_f \pm 4 = V_{ac\,404,412} = \frac{0.104 \times 226.27}{\sqrt{2}} = 16.64\ V_{RMS}$

$3m_f \pm 6 = V_{ac\,402,414} = \frac{0.016 \times 226.27}{\sqrt{2}} = 2.56\ V_{RMS}$

$4m_f \pm 1 = V_{ac\,543,545} = \frac{0.105 \times 226.27}{\sqrt{2}} = 16.8\ V_{RMS}$

$4m_f \pm 3 = V_{ac\,541,547} = \frac{0.115 \times 226.27}{\sqrt{2}} = 18.40\ V_{RMS}$

$4m_f \pm 5 = V_{ac\,539,549} = \frac{0.084 \times 226.27}{\sqrt{2}} = 13.44\ V_{RMS}$

$4m_f \pm 7 = V_{ac\,537,551} = \frac{0.017 \times 226.27}{\sqrt{2}} = 2.72\ V_{RMS}$

RMS Distortion =

$$\sqrt{130.87^2 + 2(35.2)^2 + 2(50.24)^2 + 2(22.24)^2 + 2(2.08)^2 + (27.36)^2 + 2(28.16)^2 + 2(16.64)^2 + 2(2.56)^2 + 2(16.79)^2 + 2(18.40)^2 + 2(13.44)^2 + 2(2.72)^2}$$

$= 173.70$

$\therefore THD = \frac{173.70}{127.99} \times 100 = \boxed{135.70\%}$

$3m_f \pm 2 = i_{ac\,406,410} = \frac{V_{ac\,406,410}}{R + j\omega L} = \frac{28.16}{6 + j(60 \times 136 \times 3 \times 2\pi \times 0.001)} = 0.274\ A_{RMS}$

$3m_f \pm 4 = i_{ac\,404,412} = \frac{V_{ac\,404,412}}{R + j\omega L} = \frac{16.64}{6 + j(60 \times 136 \times 3 \times 2\pi \times 0.001)} = 0.161\ A_{RMS}$

$3m_f \pm 6 = i_{ac\,402,414} = \frac{V_{ac\,402,414}}{R + j\omega L} = \frac{2.56}{6 + j(60 \times 136 \times 3 \times 2\pi \times 0.001)} = 0.025\ A_{RMS}$

$4m_f \pm 1 = i_{ac\,543,545} = \frac{V_{ac\,543,545}}{R + j\omega L} = \frac{16.80}{6 + j(60 \times 136 \times 4 \times 2\pi \times 0.001)} = 0.1635\ A_{RMS}$

$4m_f \pm 3 = i_{ac\,541,547} = \frac{V_{ac\,541,547}}{R + j\omega L} = \frac{18.40}{6 + j(60 \times 136 \times 4 \times 2\pi \times 0.001)} = 0.179\ A_{RMS}$

$4m_f \pm 5 = i_{ac\,539,549} = \frac{V_{ac\,539,549}}{R + j\omega L} = \frac{13.44}{6 + j(60 \times 136 \times 4 \times 2\pi \times 0.001)} = 0.1308\ A_{RMS}$

$4m_f \pm 7 = i_{ac\,537,551} = \frac{V_{ac\,537,551}}{R + j\omega L} = \frac{2.72}{6 + j(60 \times 136 \times 4 \times 2\pi \times 0.001)} = 0.0265\ A_{RMS}$

RMS distortion =

$\sqrt{\Sigma (I_{RMS} \text{ without fundamental})^2}$ ← repeat same as Vdist, sum all values above

$= 2.70A$

$\therefore THD = \frac{2.70}{21.29} \times 100 = \boxed{12.68\%}$