March 2024

Computer Simulation, Analysis and Education Using PLECS

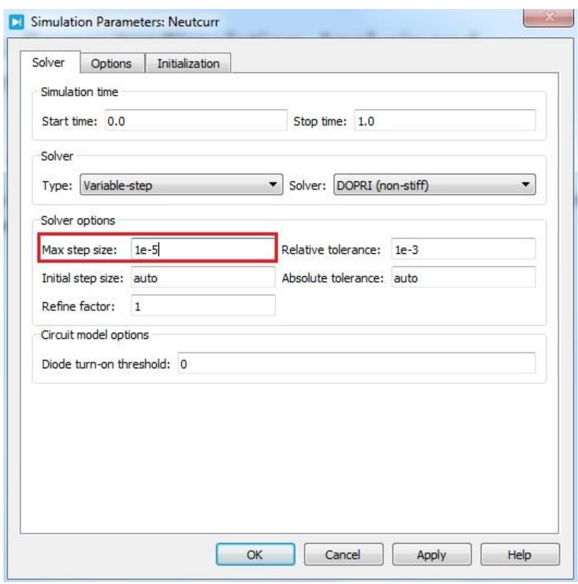
General instructions for using PLECS

Learning to use PLECS

The models needed in these simulations are ready, so you don't need to create them from scratch. Separate files ending with .plecs are provided together with this guideline. Every separate simulation task lists the exact name of the file to be used.

However, you need to add for example voltmeters, amperemeters and Scope to see and analyze the waveforms. Therefore, it is useful if you have no earlier experience on PLECS to have a look on this tutorial available o PLEXIM ww-page. Introduction to PLECS Standalone | Plexim It already has some guidance on how to use the Scope but there is more detailed tutorial too Using the PLECS Scope | Plexim and you should also have a look on this. Further, there are several other interesting tutorials for those who want to learn PLECS more Tutorials | Plexim but these are not needed in these assignments.

To ensure smooth waveforms in the simulations, the max step size value needs to be changed from auto to 1e-5. This option can be found from Simulation -> Simulation parameters. The max step size is in solver tab as shown below.



The simulation takes some time to reach steady state operation. In the beginning of the simulation, transients can be seen in the waveforms. Therefore, make sure you simulate the circuit long enough to reach steady state operation. The simulation time can be adjusted from the same menu as the max step size.

Some circuits use parameters as component values. These can be adjusted from Simulation -> Simulation parameters -> Initialization.

Values in PLECS are peak values. Often the problems request RMS (root mean square) values so you need calculate them separately.

Fourier analysis can be used from the scope block by pressing . Remember to adjust your center frequency accordingly to obtain correct results. If you are analyzing grid currents, it is often 50 Hz and with inverters e.g output frequency.

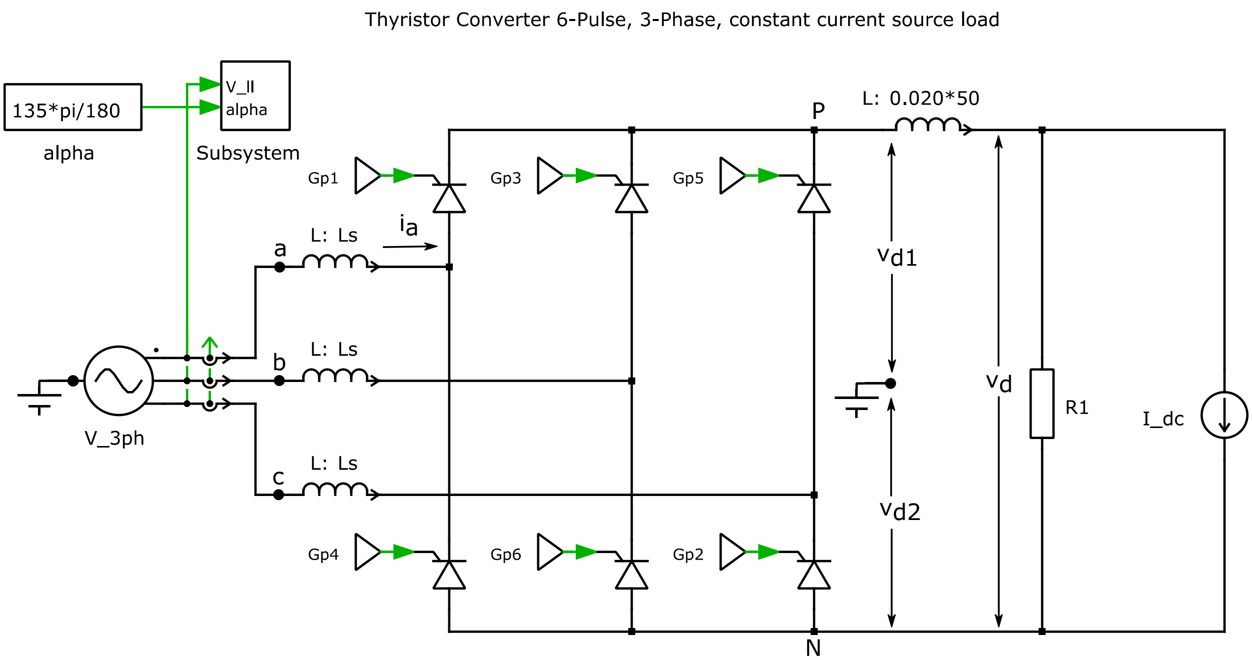
Problems often request you to different include waveforms. In your images, zoom in and only include some periods of the waveform in your image (max 10 periods). Do not include the whole simulation waveform since it is impossible to see the interesting phenomena that way.

Often it is beneficial to add multiple waveforms to the same scope screen. This can be done with the Signal multiplexer block.

To export waveforms to your document, you can copy the image to your clipboard from the scope by going to Edit -> Copy. Another option is to export the image as Bitmap or CSV through File -> Export -> as Bitmap or as CSV. With Bitmap set the quality to 100, use anti-aliasing, and set resolution to 150 dpi to obtain nice and clear figures. CSV files can be imported for example to MATLAB and plotted there.

1. Basic Concepts in 3-Phase Thyristor converters

File to be used in simulations: Thy3_Concepts.plecs



Nominal values:

$V_{LL} = 400\ V\ at\ 50\ Hz$

$L_s = 1\ mH$ (this is the supply side grid inductance)

$L_{s2} = 0.8\ H$ (Large dc-side inductance)

$R_{load} = 500\ \Omega$

$\alpha = 45°, 90°\ and\ 135°$ (use radians in the simulator)

Circuit description: The circuit is a 3-phase thyristor rectifier bridge. On the load side, a large inductor and current source are added to model close to ideal behavior of the circuit.

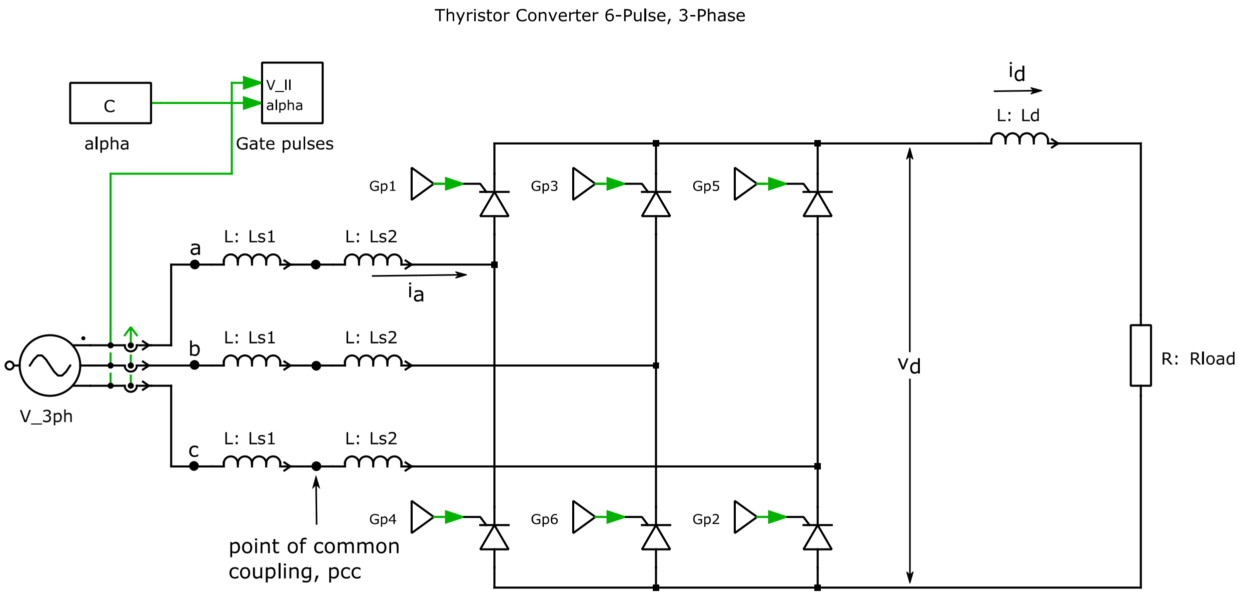
Problems

1. Execute Thy3_Concepts to obtain v_{d1} waveforms for the three values of the delay angle α (note in teaching material α_f) by changing the value of alpha block (Note: use radians). Calculate its average values by using the simulator.
2. Obtain v_{d2} waveforms like in Problem 1. Calculate its average values.
3. Obtain v_d waveform. Calculate with simulator the average value of the dc-side voltage for the three values of the delay angle α. Compare this with the theoretical value obtained by integration, see lecture material for the equation.

4. Obtain v_a and i_a waveforms. Here v_a and i_a are the grid side line-to-neutral voltage, and line current. Calculate the displacement input power factor for the three values of the delay angle α. Are they as expected by the theory?

2. 3-Phase Thyristor Rectifier Bridge

File: Thyrect3.plecs



Nominal values:

$V_{LL} = 400\ V\ at\ 50$ Hz (rms value of the line-to-line voltage)

$L_{s1} = 0.2$ mH in the grid side we are having to inductances in series

$L_{s2} = 1.0$ mH

$L_d = 16$ mH, filtering inductance in the dc-bus

$R_{load} = 8\ \Omega$

$\alpha = 45°$(check that the model uses this value)

Circuit description: A 3-phase thyristor rectifier bridge. There is a point of common coupling that represents a point between the grid and rectifier bridge inductance. For this reason there is two series connected inductances

Problems

1. Obtain the following waveforms for each section respectively.
   a. v_a, v_d, and i_d.
   b. v_a and i_a.
   c. (v_a)pcc, (v_{ab})pcc, and i_a.
2. From the plots, obtain the commutation interval u and i_d at the start of the commutation. Verify the following commutation equation:

$$\cos(\alpha + u) = \cos\alpha - \frac{2\omega L_s}{\sqrt{2}V_{LL}} I_d$$

where $L_s = L_{s1} + L_{s2}$. For I_d, use the average value of i_d or its value at the start of the commutation.

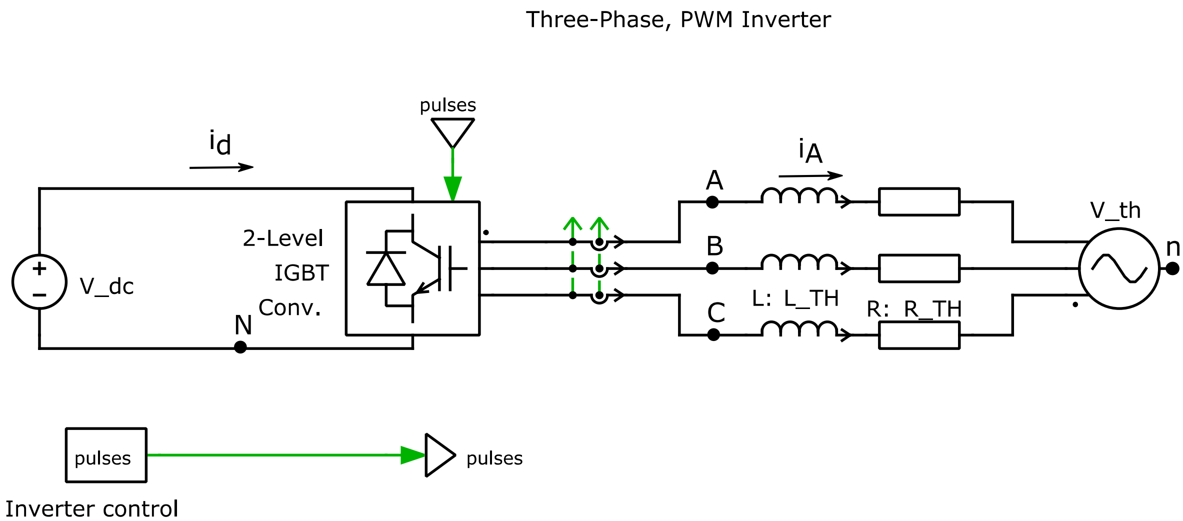
3. By means of Fourier analysis of i_a, calculate its harmonic components as a ratio of I_{a1}.
4. Calculate rms value I_a, the input displacement power factor and the input power factor.
5. At the point of common coupling, obtain the following from the v_{pcc} waveform:
    a. Line-notch depth $\rho(\%)$
    b. Line-notch area
6. Obtain the average dc voltage V_d. Verify that

$$V_d = 1.35\, V_{LL} \cos\alpha - \frac{3\omega L_s}{\pi} I_d$$

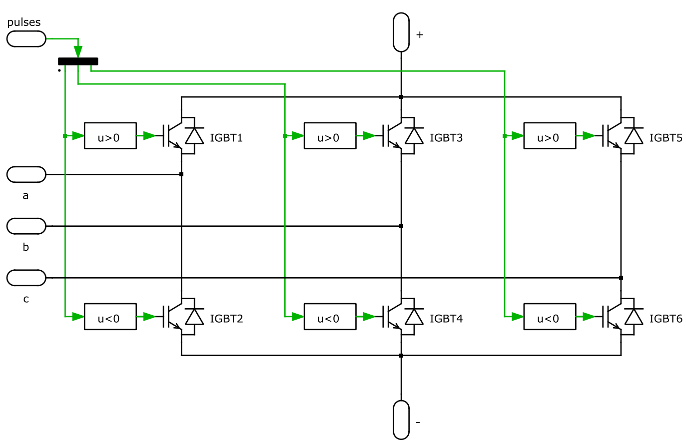
For I_d, use the average value of i_d or its value at the start of the commutation.

3. Three-Phase, PWM Inverter

File: PWINV3.plecs



Inside the 2-Level IGBT Conv. –block there is the circuit shown below which is a 3-phase IGBT inverter.



Nominal values:

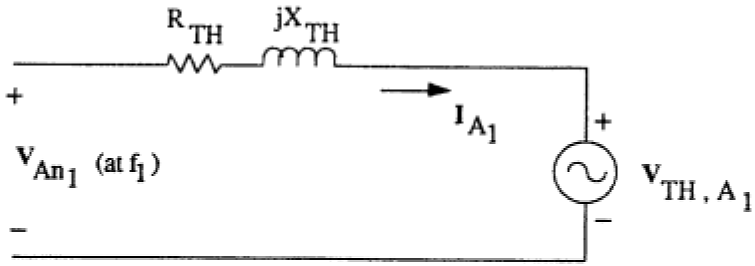
Load: A 3-phase motor operating at a frequency $f = 47.619\ Hz$. Therefore,

$$V_{LL1}^{rms} = \frac{47.619}{60} \times 230 = 182.54\ V \text{ (Note that nominal frequency used here is 60 Hz)}$$

$$V_{An1}^{rms} = \frac{V_{LL1}^{rms}}{\sqrt{3}} = 105.39\ V$$

$I_{A1}^{rms} = 10$ A at a lagging power factor of 0.866 = 10 ∠-30⁰ A. $R_s = 2\ \Omega$, $L_s = 10\ mH$, $X_s = 2\pi \times 47.619 \times 10 \times 10^{-3} = 3\Omega$.

Phasor diagram:



$\left(V_{TH,A}\right)_1$ = 74.76∠(−12.36)° V (rms)

Inverter and Sinusoidal PWM Controller:

Switching frequency $f_s = 1\ kHz$.

Amplitude modulation ratio $m_a = 0.95$.

$V_d = \frac{V_{LL1}^{rms}}{0.612\ m_a} = 313.97\ V$. With $\hat{V}_{tri} = 1.0\ V$.

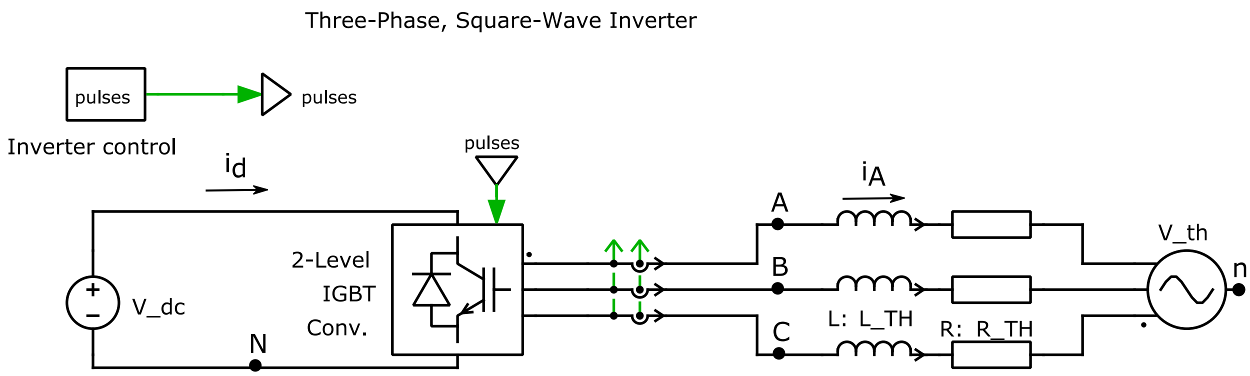
$v_{control,A} = 0.95 \sin 2\pi f_1 t\ V$.

Problems

1. Obtain the following waveforms:
    a. v_{AN} and i_A.
    b. v_{an} and i_A.
    c. v_{AN} and i_d.
2. Obtain v_{An1} by means of Fourier analysis of the v_{An} waveform. Compare v_{An1} with its precalculated nominal value.
3. Using the results of Problem 2, obtain the ripple component v_{ripple} waveform in the output voltage. Note: there is no straightforward way to get the v_{ripple} from the simulator. Use the peak value v_{An1} from Problem 2 and use sin voltage generator of PLECS to produce v_{An1} waveform in time domain and subtract it from v_{An}. Be careful with the possible phase shift in the waveforms.
4. Obtain i_{A1} by means of Fourier analysis of i_A waveform. Compare i_{A1} with its precalculated nominal value.
5. Using the results of Problem 4, obtain the ripple component i_{ripple} in the output current. Note: use the same technique as in Problem 3.
6. Obtain average value of the dc bus current $I_d(avg)$ by means of Fourier analysis and obtain the high frequency ripple $i_{d,ripple} = i_d - I_d(avg)$ in the input current.
7. Obtain the load neutral voltage with respect to the mid-point of the dc input voltage.

4. Three-Phase, Square-Wave Inverter

File: SQINV3.plecs

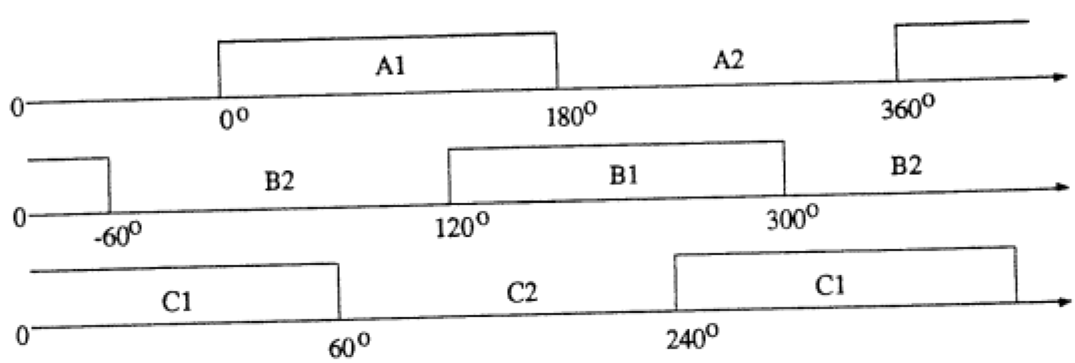


Nominal values: Same as in Exercise 3, except

$$V_d = \frac{182.54}{0.78} = 234.03$$

Where $V_{LL1}^{rms} = 182.54\,V$.

Controller:



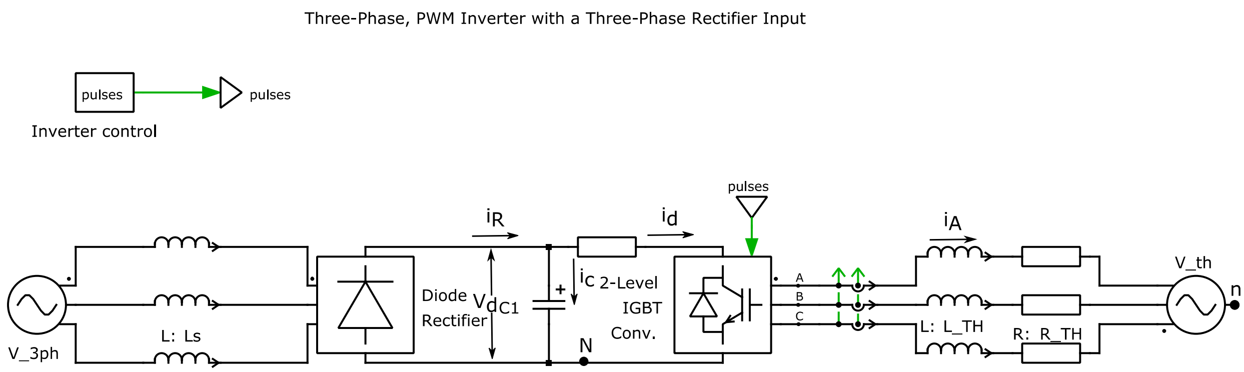
Problems

1. Obtain the following waveforms:
   a. v_{AN} and i_A.
   b. v_{an} and i_A.
   c. v_{AN} and i_d.
2. Obtain v_{An1} by means of Fourier analysis of the v_{An} waveform. Compare v_{An1} with its precalculated nominal value.
3. Using the results of Problem 2, obtain the ripple component v_{ripple} waveform in the output voltage. Note: The guidance was in previous exercise.
4. Obtain i_{A1} by means of Fourier analysis of i_A waveform. Compare i_{A1} with its precalculated nominal value.

5. Using the results of Problem 4, obtain the ripple component i_{ripple} in the output current.
6. Obtain $I_d(avg)$ by means of Fourier analysis and obtain the high frequency ripple $i_{d,ripple} = i_d - I_D(avg)$ in the input current.
7. Obtain the load neutral voltage with respect to the mid-point of the dc input voltage.

5. Three-Phase, PWM Inverter with a Three-Phase Rectifier Input

File: PWMInv3_Rect.plecs



Nominal values

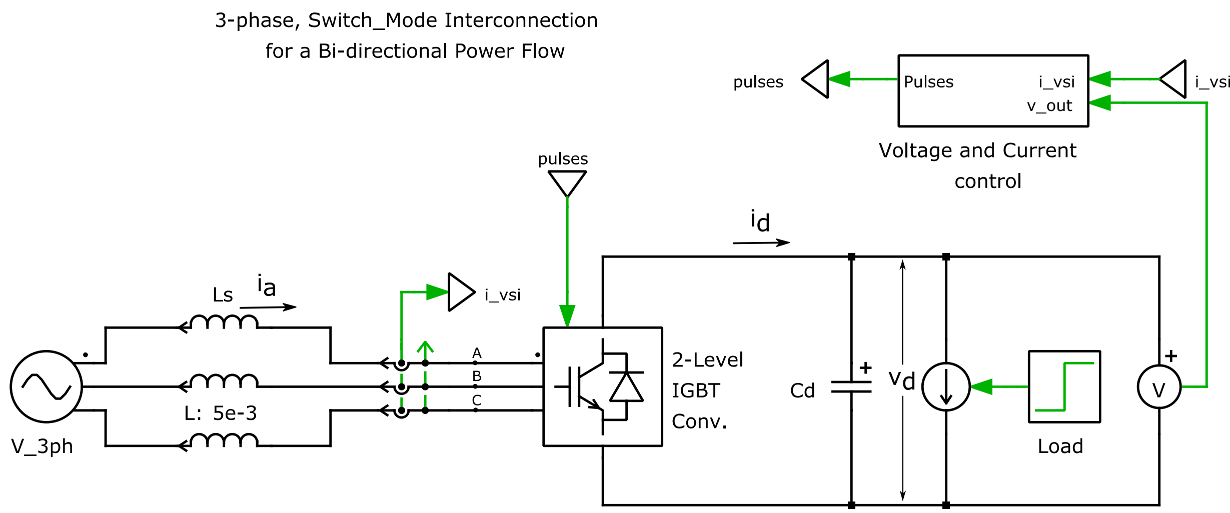
L_{TH} = = 10 mH, R_{TH} = 2 Ω, Ls = 3 mH, C1 = 500 µF

Problems

1. Obtain the following waveforms using PWMInv3_Rect:
   a. i_R, i_c and i_d.
   b. v_d.
2. Obtain the RMS values of the currents i_R, i_c and i_d.
3. Plot peak-to-peak ripple in v_d with the capacitor C_d values of 500 µF, 1000 µF and 1500 µF.
4. Change L_{TH} to 1 mH. Obtain waveforms of i_A and v_{An}. Compare to the initial value of 10 mH.

6. 3-Phase, Switch-Mode Interconnection for a Bi-directional-Power-Flow

File: 3Ph_Conn.plecs



Nominal values:

$V_{LL} = 398\,V$

$L_s = 5\,mH$

$f_s = 5\,kHz$

Problems

1. Obtain the v_s and i_s waveforms.
2. Obtain the maximum peak-to-peak ripple in i_s.
3. Obtain the fundamental frequency component of the converter voltage v_{conv1}. What is the angle by which it lags v_s.
4. Obtain the waveform of the dc-side current i_d.
5. Repeat Problems 1 through 4 by increasing L_s from 5 mH to 10 mH.