ELK331E - Power Electronics Circuits HW1

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1 Calculating RL Load Values

To design an RL load that corresponds to a 50 kVA load with 480 V RMS line-to-line voltage, we need to calculate the appropriate resistance (R) and inductance (L) values. The following steps outline the process of how to calculate these values.

Setting the parameters:

- Apparent Power (S) = 50 kVA = 50,000 VA
- Line-to-Line Voltage V_{line} = 480 V RMS
- Frequency (f) = 60 Hz
- Power Factor $\cos\phi = 0.8$ (for an inductive load)

Step 1: Calculate the Total Impedance (Z)
From the formula for apparent power in a three-phase system:

$$S = \frac{V_{line}^2}{Z} \cdot \frac{1}{\sqrt{3}}$$

Rearrange to solve for Z:

$$Z = \frac{V_{line}^2}{S \cdot \sqrt{3}}$$

Substitute the known values:

$$Z = \frac{480^2}{50,000 \cdot \sqrt{3}} = \frac{230,400}{86,602.54} \approx 2.66\,\Omega$$

So, the total impedance Z required to achieve 50 kVA of apparent power is 2.66 .

Step 2: Calculate the Resistance (R) and Inductive Reactance X_L
Since the load is resistive-inductive (RL), the impedance Z is given by:

$$Z = \sqrt{R^2 + X_L^2}$$

Where: - R is the resistance. - $X_L = \omega L$ is the inductive reactance. - $\omega = 2\pi f$ is the angular frequency.

We can now decompose the impedance into resistive and reactive components.

Step 3: Calculate the Power Factor Angle ϕ
From the power factor, we know:

$$\cos\phi = 0.8$$

Thus, the phase angle ϕ is:

$$\phi = \cos^{-1}(0.8) \approx 36.87^\circ$$

Step 4: Calculate the Resistance (R)
The resistance (R) is given by:

$$R = Z \cdot \cos\phi$$

Substitute the values:

$$R = 2.66 \cdot 0.8 = 2.13\,\Omega$$

Step 5: Calculate the Inductive Reactance X_L
The inductive reactance X_L is given by:

$$X_L = Z \cdot \sin\phi$$

Substitute the values:

$$X_L = 2.66 \cdot \sin(36.87^\circ) = 2.66 \cdot 0.6 = 1.60\,\Omega$$

Step 6: Calculate the Inductance (L)
Finally, we calculate the inductance (L) using the formula:

$$X_L = \omega L$$

Where:

$$\omega = 2\pi f = 2\pi \cdot 60 = 377\,rad/s$$

Now, solve for L:

$$L = \frac{X_L}{\omega} = \frac{1.60}{377} \approx 0.00424\,H = 4.24\,mH$$

- Resistance $R = 2.13$
- Inductive Reactance $X_L = 1.60$
- Inductance $L = 4.24$ mH
- Total Impedance $Z = 2.66$

Summary:
To achieve 50 kVA of apparent power with a 480 V RMS line-to-line voltage and a power factor of 0.8, the required values for R and L are:

- **Resistance (R)** = 2.13
- **Inductance (L)** = 4.24 mH

2 Simulink Circuit of 6 Pulse Diode Rectifier

The **6-pulse diode rectifier** circuit is an essential component in power electronics for converting three-phase AC to DC. In this project, the **Simscape** library was used to model the 6-pulse rectifier, consisting of six diodes arranged in a bridge configuration. This configuration rectifies the three-phase AC input into a pulsating DC output, which is then filtered to provide a smooth DC voltage.

In the **6-pulse rectifier**, three-phase AC voltage sources are used, connected to the anodes of the diodes. The cathodes of the diodes are connected to the load, which consists of a resistive-inductive (RL) load. The diodes are triggered in a sequence such that each pair of diodes conducts during the positive half-cycle of the respective phases, allowing the current to flow in the proper direction.

Here is an image of the **6-pulse rectifier topology** using the **Simscape library**:

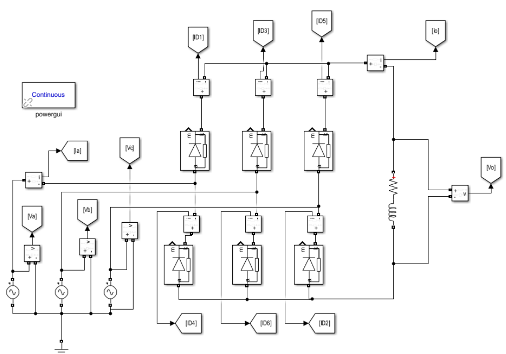

Figure 1: Six-Pulse Diode Rectifier Topology

This topology shows the configuration of the six diodes in the bridge arrangement. The three-phase AC supply is fed to the anodes of the diodes, and the load is connected to the cathodes. The diodes conduct in pairs, with each pair conducting for a third of the input AC waveform, ensuring that current always flows in one direction to the load.

The line-to-line voltage of the three-phase system is set to **480 V RMS**, as mentioned earlier. The calculated load values, including a resistance of **2.13** and inductance of **4.24 mH**, are applied to this rectifier circuit.

Voltage Waveform:

The output voltage of the rectifier is plotted in the graph below, showing the DC voltage after rectification. The graph represents the output voltage between **580 V** and **680 V**. This corresponds to the rectified DC output from the three-phase input voltage.

Commentary on the Voltage Waveform: The voltage waveform shows the typical ripple seen in the output of a 6-pulse rectifier. The voltage fluctuates

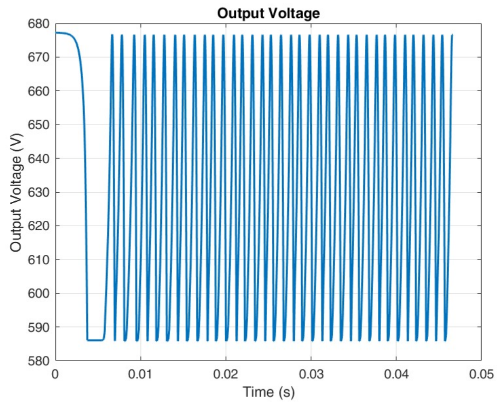

Figure 2: Output Voltage Waveform of the 6-Pulse Rectifier

between **580 V** and **680 V**, which is expected for this type of rectification. The peaks in the waveform represent the points where the diodes switch between phases, and the valleys show the transition between conducting pairs of diodes. Filtering can further smooth the DC output for applications that require a constant DC supply.

Current Waveform:

The output current waveform of the rectifier is shown below. After the transient state, the current stabilizes around **300 A**, which was the desired current for this rectifier design.

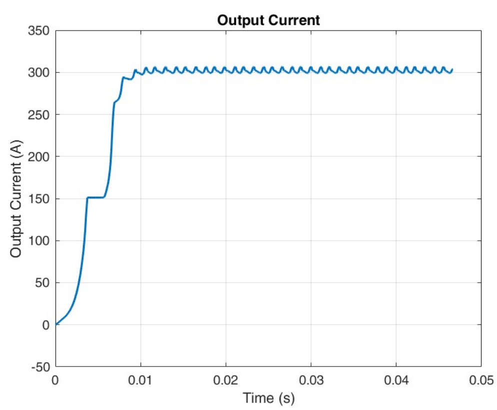

Figure 3: Output Current Waveform of the 6-Pulse Rectifier

The current waveform stabilizes around **300 A** after the transient period. This is consistent with the expected current for the load. The current waveform also shows the typical behavior of a rectified current, where it has a ripple due to the pulsating nature of the rectified DC output. Although the current is not perfectly constant, it is within an acceptable range for the desired application. The diodes' current waveforms, available in the scope but not transferred to the workspace, also show the individual current flows through each diode, which can be analyzed for more detailed performance monitoring.

The rectifier design meets the expected criteria, providing a stable current and voltage for the connected load.

I calculated manually the THD (Total Harmonic Distortion) values for the signals Va (Phase A voltage), Io (Output current), and Vo (Output voltage). Initially, I tried to use the built-in `thd()` function in MATLAB, but I encountered errors I could not resolve. Once I manually calculated the THD values, the results were as follows:

- THD for Va (Phase A Voltage): 11.4578% - Va represents the phase A voltage or line-to-line voltage. - A THD of 11.4578% means that the voltage waveform has approximately 11.46% harmonic distortion. This indicates that while the voltage waveform is relatively clean, it does contain noticeable harmonic components.

- THD for Io (Output Current): 1.5229% - Io is the output current of the rectifier circuit. - A THD of 1.5229% indicates that the current waveform is close to a pure sinusoidal wave, with only a small amount of harmonic distortion. Lower THD in current is typically desirable as it minimizes losses and improves system efficiency.

- THD for Vo (Output Voltage): 11.4178% - Vo is the output voltage of the rectifier circuit. - A THD of 11.4178% means the output voltage waveform is similar to the phase A voltage in terms of harmonic distortion, showing noticeable but acceptable levels of harmonic content in typical rectifier systems.

3 Circuit of 24 Pulse Diode Rectifier

A **24-pulse diode rectifier** circuit is an advanced version of the typical 6-pulse rectifier that reduces the ripple content in the rectified output. In contrast to the 6-pulse rectifier, the 24-pulse rectifier uses a **24-pulse phase-shifting transformer**, which allows for more phases to be added to the system, resulting in finer control of the current and a smoother DC output.

In my research, I found that **MATLAB 2024b** introduced a new feature that supports the **24-pulse phase-shifting transformer**, a key component in building this rectifier. To model this rectifier circuit in MATLAB, I updated my MATLAB version to access this new functionality.

The 24-pulse rectifier circuit consists of **24 diodes** arranged in a specific configuration with a **phase-shifting transformer** that shifts the phases by specific amounts, creating 24 distinct phases. This results in smoother rectified output because the greater number of pulses significantly reduces the harmonic content and ripple in the DC output.

Here is an image of the **24-pulse rectifier topology** using the **phase-shifting transformer**:

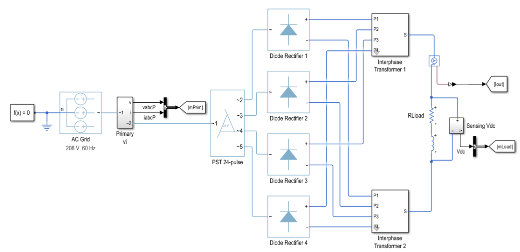

Figure 4: 24-Pulse Diode Rectifier Topology with Phase-Shifting Transformer

This topology shows the **24 diodes** arranged in a more complex configuration than the 6-pulse rectifier. The **phase-shifting transformer** is the key component that allows for the 24-phase system. Each phase is offset by a specific angle, and the transformer creates the necessary phase shifts for the rectifier to produce smoother DC output.

Voltage, Current, and DC-Link Voltage Waveform:

The graph below shows the voltage and current waveforms, as well as the **DC-link voltage**, which is the output voltage after rectification. The DC-link voltage stabilizes around **500 V**, which is typical for this type of rectifier.

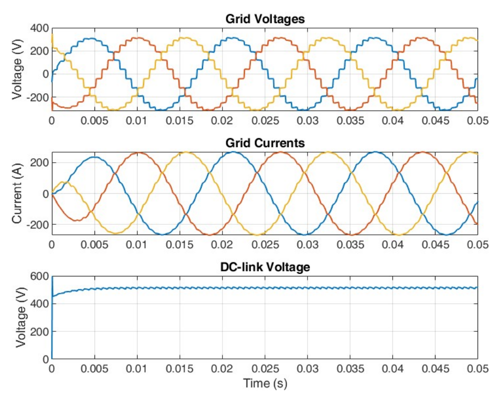

Figure 5: Grid Voltages, Grid Currents, and DC-Link Voltage

Commentary on the Waveform: The graph includes three key components: - **Grid voltages**: The AC input voltages before rectification, shown as sinusoidal waveforms. - **Grid currents**: The currents drawn from the grid, showing how the rectifier affects the power draw. - **DC-link voltage**: This is the rectified DC voltage, and it stabilizes around **500 V**, which is the expected value after rectification. This smoother DC output is made possible by the 24-pulse system and the phase-shifting transformer.

The introduction of the **phase-shifting transformer** allows the 24-pulse rectifier to produce a much smoother DC output compared to the 6-pulse rectifier. The reduction in ripple significantly improves the performance of the system, making it more suitable for applications that require stable DC voltage with minimal fluctuation.

Issues with THD Calculation and Rectified Output Waveform:

I attempted to calculate the THD values for the output current (I_{out}) of the 24-pulse rectifier, but I kept encountering errors when trying to calculate it. I tried using the `thd()` function, but it was not working as expected. However, I was able to get the output waveform displayed in the scope.

Here is the image showing my attempt to calculate I_{out}:

```
Iout = simlog.Iout;
plot(t, Iout.values, 'LineWidth', 1)
grid on
title('Output Current (Iout)')
ylabel('Current (A)')
```

Figure 6: Attempt to Calculate I_{out} in MATLAB

Despite the errors in calculating THD, the waveform displayed in the scope was successfully rectified as expected. The output current waveform, shown below, was rectified properly and stabilized as anticipated:

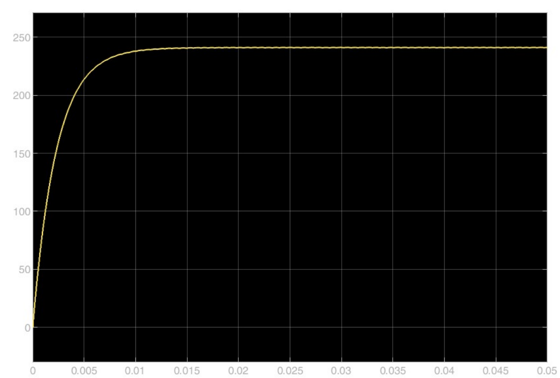

Figure 7: Rectified Output Current Waveform (I_{out})

Although I did not manage to plot the output current through "To Workspace" block, I got the graph in Figure 7. The rectified output current waveform, as seen, shows the expected smoothing and rectification after the phase shifts from the 24-pulse rectifier.

4 Comparing 6 and 24 Pulse Rectifiers

The comparison between the 6-pulse and 24-pulse rectifiers highlights the improvements in efficiency, harmonic distortion, and output smoothness with the introduction of additional phases in the 24-pulse system.

- Harmonic Distortion: The primary advantage of the 24-pulse rectifier over the 6-pulse version is the significant reduction in harmonic distortion. The 24-pulse system produces a much smoother DC output because the phase-shifting transformer divides the system into more phases, resulting in a higher number of pulses in the rectified output. This results in lower Total Harmonic Distortion (THD), which is especially important for reducing power losses and improving the overall system efficiency.

- Efficiency: The increased number of pulses and the resulting smoother DC output in the 24-pulse rectifier improves efficiency in power conversion. The 6-pulse rectifier, while simpler, is less efficient because of its higher ripple content and more significant harmonic distortions.

- Ripple Reduction: The ripple in the DC output is much smaller in the 24-pulse rectifier, making it more suitable for applications that require stable DC voltage, such as high-precision electronics or industrial motor drives.

In conclusion, while the 6-pulse rectifier is simpler and can be used in many applications with acceptable performance, the 24-pulse rectifier offers superior performance in terms of harmonic distortion, efficiency, and output quality, making it ideal for more demanding applications.

References

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