The LCL filter design for three phase DC-AC voltage converter

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Abstract. This paper discusses LCL filter design to apply for a three phase DC-AC converter from a DC source of distributed generator to a three phase power system. System is transformer less, using H-bridge switching with 6 IGBTs, modelled by using PSIM to deliver 20 kW 400V source to a three phase 380 V 50 Hz system. The LCL filter requires inductors 518.564 µH and 311.13 µH, capacitor of 65.74µF. The loss resistance is 0.573 Ohm. The LCL filter is able to smooth DC-AC converter output starts from 0.005 s.

1. Introduction

DC-AC converter that is connected to power grid, uses pulse width modulation (PWM) that generates sinusoidal waveform with additional harmonics in its output. Many conversion technologies are available [1], including low current application [2]. However, filter holds the important role. Filter is generally employed to suppress the harmonics in the generated AC voltage. Filter reduces high frequency switching and protects load from transient voltage [3].

There are three type of filter employed for DC-AC converter, namely: L filter, LC filter, and LCL filter LCL [4]. Figure 1 shows various basic circuits of the aforementioned filter types. The L and LC filters perform best in voltage-current conversion but worst in working on high frequency waveform. Meanwhile, the LCL filter has good response to current ripple even with small inductance [3]. Beside losses characteristics, LCL decouples circuit to grid better than other two filters. The LCL filter loss is about -60 dB/decade [4]. The main disadvantage is its impedance as it uses two inductors [5].

![Filter circuits](image)

Figure 1. Filter circuits

The components calculations, converter side inductor (L1), grid side inductor (L2), and filter capacitance (Cf) have been approximated to reduce high order harmonics [6, 7].

\[ Z_b = \frac{E_n^2}{P_n} \]  

(1)
The values of $L_1$, $L_2$ and $C_f$ are given by Equation 4, 5 and 6. Value $\Delta I_{L_{\text{max}}}$ is approximated about 10% of maximum current. Value $r$ is the ratio of $L_2$ and $L_1$, $r = 0.6$ gives power factor reduction of 5% [33]. The $\omega_{\text{res}}$ is the resonance frequency in radian and $R_f$ is losses resistance. In order to avoid resonance for low and high order harmonics, resonant frequency should be smaller than 50% of switching and greater than 10 times of grid frequency [9],

$$L_1 = \frac{V_{\text{DC}}}{6 \cdot F_{\text{sw}} \cdot \Delta I_{L_{\text{max}}}} \quad (4)$$

$$C_f = 0.05 \cdot C_b \quad (5)$$

$$L_2 = r \cdot L_1 \quad (6)$$

$$\omega_{\text{res}} = \sqrt{\frac{L_1 + L_2}{L_1 \cdot L_2 \cdot C_f}} \quad (7)$$

$$R_f = \frac{1}{3 \cdot C_f \cdot \omega_{\text{res}}} \quad (8)$$

2. System Modelling

In order to examine the effectiveness of the LCL filter to reduce harmonics within the designed DC-AC converter, a designed model is examined at first place, giving the final model as shown in Figure 2, simulated by PSIM simulator. The designed DC-AC converter comprises DC source, H-Bridge, SPWM, current controller, phase lock loop and LCL filter. The LCL filter is inserted in between H-bridge and load as shown in Figure 3.

Figure 2. Designed system
3. Simulation results

In order to determine filter components, the following data is required: output phase voltage \( E_n \), active power \( P_n \), source voltage \( V_{dc} \), grid frequency \( f_g \), and switching frequency \( f_{sw} \). If the output voltage is expected in 380 V/50Hz with modulation amplitude of SPWM \( m_a = 0.9 \), then the source voltage is about:

\[
V_{DC} = \frac{2 \cdot V_{pk} \cdot \sqrt{2}}{m_a \cdot \sqrt{3}} = \frac{2 \cdot 220 \cdot \sqrt{2}}{0.9 \cdot \sqrt{3}} = 399.176V = 400V
\]

The source capacitance is calculated based on source voltage (400V), grid frequency (50 Hz) and active power (20 KW). While the basic impedance \( Z_b \), basic capacitance and maximum current are calculated based on \( E_n, P_n \) and \( f_g \):

\[
C = \frac{4 \cdot P_n}{4 f_g V_{dc}^2} = \frac{4 \cdot 20,000}{400^2} \cdot 5 \cdot 10^{-3} = 2500\mu F
\]

\[
Z_b = \frac{E_n^2}{P_n} = \frac{220^2}{20,000} = 2.42\Omega
\]

\[
C_b = \frac{1}{\omega g Z_b} = \frac{1}{2\pi \times 50 \times 2.42} = 0.0013148F
\]

\[
I_{max} = \frac{P_n \cdot \sqrt{2}}{3V_{ph}} = \frac{20,000 \times \sqrt{2}}{220} = 128.56A
\]

By using \( \Delta I_{L_{max}} \) 10% of \( I_{max} \), the \( L_1, L_2 \) and \( C_f \) are determined by using Equation 1, 2, and 3.

\[
L_1 = \frac{V_{DC}}{6 \cdot F_{sw} \cdot \Delta I_{L_{max}}} = \frac{400}{6 \times 10,000 \times 12.856} = 518.564\mu H
\]

\[
C_f = 0.05 \cdot C_b = 0.05 \times 0.0013148 = 65.74\mu F
\]

\[
L_2 = r \cdot L_1 = 0.6 \times 518.564\mu H = 311.13\mu H
\]

\[
\omega_{res} = \sqrt{\frac{L_1 + L_2}{L_1 \cdot L_2 \cdot C_f}}
\]

\[
f_{res} = \frac{\omega_{res}}{2\pi} = \frac{8.8444737 \times 10^3}{2 \times \frac{22}{7}} = 1.40707 \times 10^3 \text{ Hz}
\]
The calculated resonant frequency is in between 10 times of grid frequency and 0.5 times of switching frequency. The losses resistance is then calculated.

\[ R_f = \frac{1}{3 \cdot C_f \cdot \omega_{res}} = 0.5732 \Omega \]

The filter response is shown in Figure 4. Perfect phase response is obtained when losses resistance is zero, but the magnitude of resonance frequency at peak more than 100 dB for this condition.

Figure 4. Filter response

Figure 5 shows the DC-AC converter output with good response after 0.005 s. Waveform is quite smooth with low level noise in three voltages.

Figure 5. DC-AC converter output
4. Conclusions

Synchronous distributed generator voltage waveform is important to maintain stability when connected to power grid. The filter design is important to ensure DC-AC conversion from DC source of distributed generator such as solar panel to make sure the exported voltage is in line to the standard. This paper has presented the LCL filter design to smoothen DC-AC converter from a DC source to a 380 V/50 Hz three phase system. Filter is designed to deliver 20 kW power from a 400 V DC source with maximum current 128.46 A. As results, LCL filter requires inductors 518.564 µH and 311.13 µH, capacitor of 65.74 µF. The loss resistance is 0.573 Ohm that makes the magnitude surges more than 100 dB at resonant frequency. The DC-AC with the designed LCL achieves smooth output at 0.005 s.

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