Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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

To cite this article: S Hasan *et al* 2021 *J. Phys.: Conf. Ser.* **1783** 012067

Journal of Physics: Conference Series **1783** (2021) 012067 doi:10.1088/1742-6596/1783/1/012067

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

S Hasan[1], Suherman[1*], D P Saragi[1], Y Siregar[1], M Al-Akaidi[2]

[1]Electrical Engineering Department, Universitas Sumatera Utara, Medan-Indonesia
[2]American University in the Emirates, Dubai, UAE

[*]suherman@usu.ac.id

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].

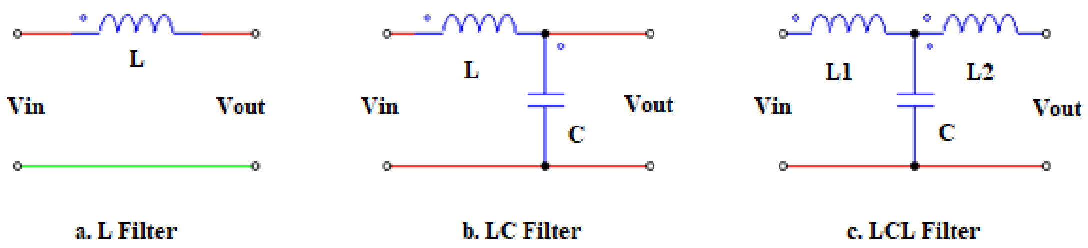

Figure 1. Filter circuits

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].

$$Z_b = \frac{E_n^2}{P_n} \tag{1}$$

$$C_b = \frac{1}{\omega_g Z_b} \tag{2}$$

$$I_{\max} = \frac{P_n \cdot \sqrt{2}}{3V_{ph}} \tag{3}$$

The values of L_1, L_2 and C_f are given by Equation 4, 5 and 6. Value ΔI_{Lmax} is approximated about 10% of maximum current. Value r is the ration of L_2 and L_1, r = 0.6 gives power factor reduction of 5% [33]. The ω_{res} is the resonance frequency in radian and Rf 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],

$$L_1 = \frac{V_{DC}}{6 \cdot F_{sw} \cdot \Delta I_{L\max}} \tag{4}$$

$$C_f = 0.05 \cdot C_b \tag{5}$$

$$L_2 = r \cdot L_1 \tag{6}$$

$$\omega_{res} = \sqrt{\frac{L_1 + L_2}{L_1 \cdot L_2 \cdot C_f}} \tag{7}$$

$$R_f = \frac{1}{3 \cdot C_f \cdot \omega_{res}} \tag{8}$$

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.

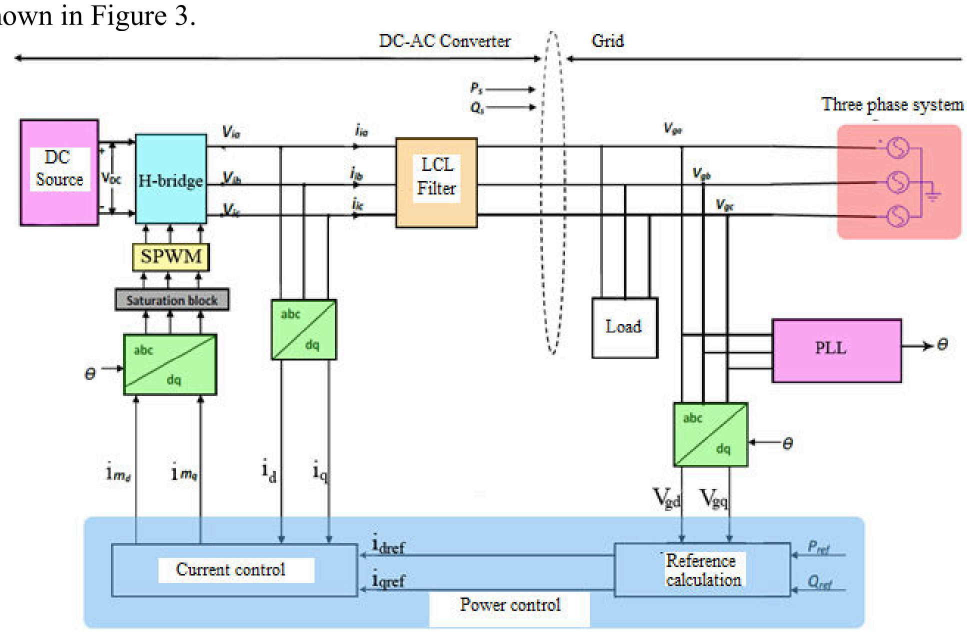

Figure 2. Designed system

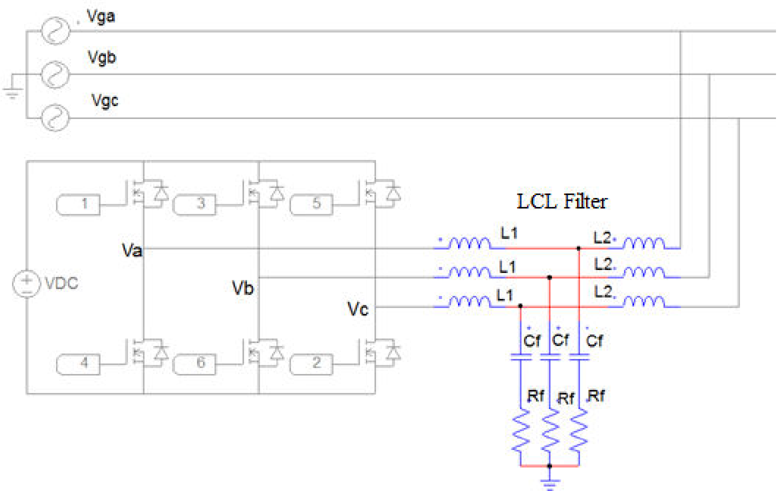

Figure 3. Filter insertion

3. Simulation results

In order to determined filter components, the following data is required: output phase voltage (En), 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:

$$V_{DC} = \frac{2 \cdot V_{nK} \cdot \sqrt{2}}{m_a \cdot \sqrt{3}} = \frac{2 \cdot 220 \cdot \sqrt{2}}{0.9 \cdot \sqrt{3}} = 399.176V = 400V$$

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.

$$C = \frac{4 \cdot P_n}{4 f_g V_{DC}^2} = \frac{4 \cdot 20.000}{400^2} 5 \cdot 10^{-3} = 2500 \mu F$$

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

$$C_b = \frac{1}{\omega_g Z_b} = \frac{1}{2\pi x 50 x 2.42} = 0.0013148F$$

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

By using ΔI_{Lmax} 10% of I_{max}, the L_1, L_2 and C_f are determined by using Equation 1, 2, and 3.

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

$$C_f = 0.05 \cdot C_b = 0.05 \times 0.0013148 = 65.74 \mu F$$

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

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

$$f_{res} = \frac{\omega_{res}}{2\pi} = \frac{8.8444737 \times 10^3}{2 \times \frac{22}{7}} = 1.40707 \times 10^3 Hz$$

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.

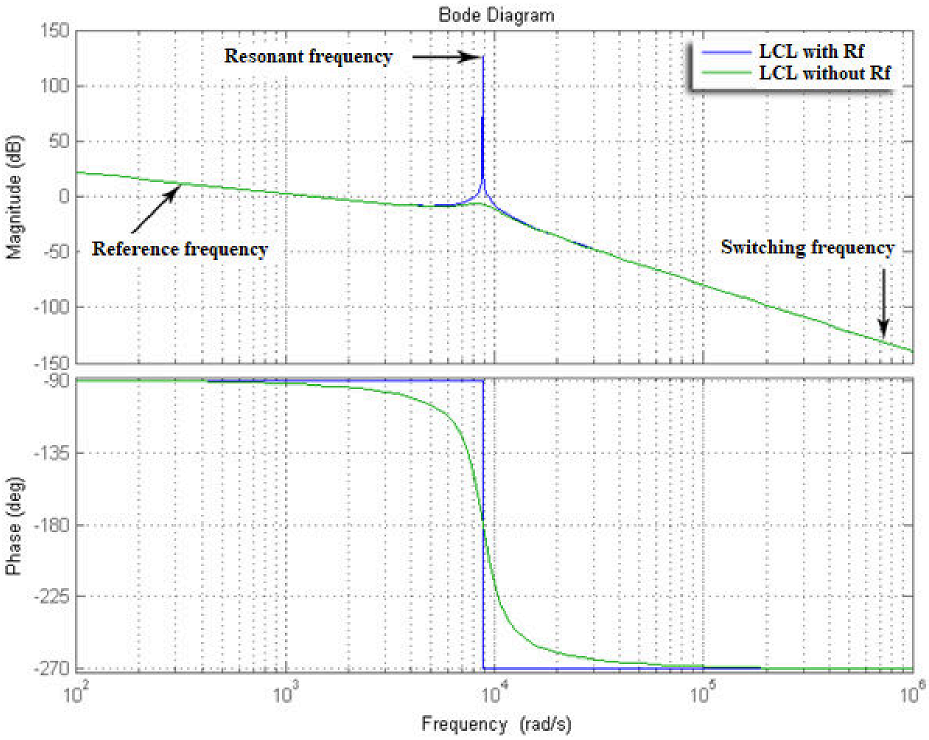

Figure 4. Filter response

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.

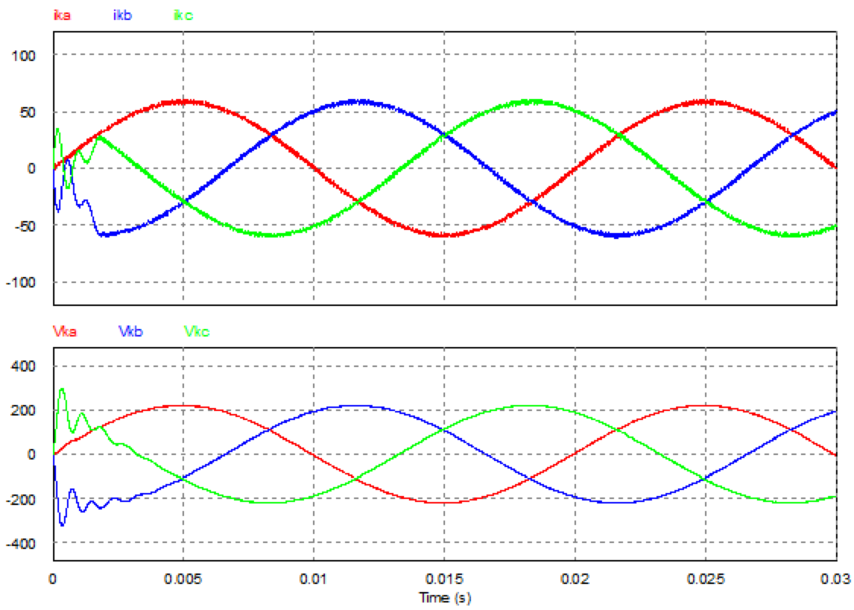

Figure 5. DC-AC converter output

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 128.46A. As results, LCL filter requires inductors 518.564 μH and 311.13 μH, capacitor of 65.74μF. 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.

References

[1] Hutabarat, M. A., Hasan, S., Rambe, A. H., & Suherman, S. (2020). Design and simulation hybrid filter for 17 level multilevel inverter. Bulletin of Electrical Engineering and Informatics, 9(3), 886-897.

[2] Dunia, A. I. M., Rambe, A. H., & Fauzi, R. (2018, March). Measuring the power consumption of social media applications on a mobile device In. In Journal of Physics: Conference Series (Vol. 978, No. 1).

[3] Islam, S. U., Zeb, K., Din, W. U., Khan, I., Ishfaq, M., Busarello, T. D. C., & Kim, H. J. (2018). Design of a proportional resonant controller with resonant harmonic compensator and fault ride trough strategies for a grid-connected photovoltaic system. Electronics, 7(12), 451.

[4] Awad, F. H., Mansour, A. A., Marei, M. I., & Sattar, A. A. (2019, November). Compensation the Unbalance of Non-Linear Load Based on Three-Leg Center-Split Inverter Four Wire. In 2019 6th International Conference on Advanced Control Circuits and Systems (ACCS) & 2019 5th International Conference on New Paradigms in Electronics & information Technology (PEIT) (pp. 229-236). IEEE.

[5] Runge, J. (2016). Design and control of resilient micro-inverter system (Doctoral dissertation).

[6] Adekola, O. I. (2015). Design and development of a smart inverter system (Doctoral dissertation, Cape Peninsula University of Technology).

[7] Mustafa DURSUN, M. Kenan DOSOGLU,"LCL Filter Design for Grid Connected Three-Phase Inverter," 2018 2ndInternational Symposium on Multidisciplinary Studies and Innovative Technologies, pp. 1-4 2018

[8] Reznik, A., Simões, M. G., Al-Durra, A., & Muyeen, S. M. (2013). $ LCL $ filter design and performance analysis for grid-interconnected systems. IEEE transactions on industry applications, 50(2), 1225-1232.

[9] Deng, W. S., Zhang, B. H., Ding, H. F., Shao, J., & Jin, B. J. (2013). A Method for Improving Compensation Performance of the Active Power Filter. In Advanced Materials Research (Vol. 732, pp. 1240-1246). Trans Tech Publications Ltd.