

Analysis and Design of a Passively Damping LCL Filter in Three-Phase Converters

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Abstract— This article discusses the mitigation of high-frequency harmonics through high voltage converters. First we present a generalized model of the passively cushioned LCL filter and then, the optimization process is implemented, which results in the low consumption of active and reactive energy of the capacitor resistance branch. The output characteristics of the passively amortized LCL filter are determined by three parameters of different combinations with the same output result: total L induction, the damping ratio and natural frequency. In a second time we present the design of a control line of the LCL filter on the referential theory giving rise to a simpler way the calculation of different characteristics or combinations such as peak resonance, impedance as well as certain elements that consume reactive and active energy from the RC branch of our LCL filter. The simulations were performed in the Matlab/Simulink environment. The results show a significant improvement in the harmonic attenuation rate.

Keywords—Ractive power, active power, passively damping, LCL filter, RC branch.

I. INTRODUCTION

The problem of harmonic pollution has become more and more worrying in recent decades. This is because of the increased use of so-called non-linear loads including static converters, computers, electric arc furnaces and many other devices. the LCL passive filter when it is well adapted is widely used to obtain an excellent attenuation of the high frequency harmonics. However, the resonance peak in its impedance characteristic as well as some increased consumption of active and reactive energy is observed in the series-connected RC branch is always generated [1-5]. The LCL passive filter proved to be the most effective solution for the compensation of voltage harmonics. Moreover, its performance depends on the technique used to identify the harmonic reference voltages and the control strategy implemented [6-10].

First we present a general model of the passive LCL filter and then, the optimization process is started, which results in the low consumption of active and reactive energy of the series capacitor resistor branch. The purpose of this article is to evaluate the effectiveness of different harmonic filtering means. As far as passive filtering is concerned, the

configuration of parallel resonant and damped filters is studied theoretically and by simulation with Matlab/Simulink. Many active filter configurations may be encountered, but all are based on an inverter (with power transistors and diodes), a continuous source of voltage or current, and a filtering and coupling circuit.

In the context of this article, to reduce harmonic pollution, several solutions have been developed. However, the LCL passive filter has proved to be the most efficient solution for the compensation of voltage harmonics [11], its performance depends on the technique used to identify reference harmonic voltages and the control strategy implemented. In [12], the prediction model THD was used to replace the current LCL model in order to reduce the total harmonic distortion rate, and the parameters were optimized by experimental design.

The literature [13] discusses analysis and the relationship between the performance of the LCL filter and various parameters, as well as the guiding principles of parameter design. The literature [14] introduced the genetic algorithm in the design of LCL filter parameters to obtain the optimal design. Numerous control strategies for

three-phase grid-connected have been devised to achieve accurate and fast current regulation by controlling inverter currents [10], capacitor currents [15], capacitor voltages and grid currents. However, as pointed out and controlling only one variable (single loop) does not lead to a satisfactory damping performance.

The literature [16] begins with the mathematical model of the LCL filter and proposes an intuitive graphical design method. In [17], the damping loss of the LCL filter is taken as an object of investigation and the influence of the variation of each parameter on the loss of damping is analyzed. For the design of the parameters of the LCL filter, the methods existing ones have proposed different design and optimization ideas, but there are also different degrees of defects.

First, we present a mathematical model of the passive LCL filter with a series RC branch, in a second time we present the design of a command line of this LCL filter on the referential theory giving rise to a simpler way the computation different characteristics or combinations of our LCL filter. In order to validate this study, we have developed a Simulink model, this model has the particularity of integrated parallel passive filters. The simulations were performed in the Matlab / Simulink environment and the results obtained show a significant

improvement in the harmonic distortion rate.

II. EXTERNAL CHARACTERISTICS AND OVERVIEW OF LCL FILTERS WITH PASSIVE DAMPING

The representation below is the model block containing all the elements of the LCL filter with a set of elements whose mission is to manage the different impulses of the inverter which is the block located just after the power supply.

The diagram of the figures below includes the sinusoidal three-phase power network, the non-linear charge symbolized by resistance and inductance, the tension-structured inverter, built from IGBT transistors. all the work was done on two assemblies, a global assembly so the aim was to set up a signal generator piloting the system, a unified assembly to allow us to bring out the different settings of calculations. to understand how the system works, we will do the calculations on a phase line because the three phases have the same elements, but differ signal but however, the behavior of the curves will differ depending on the load.

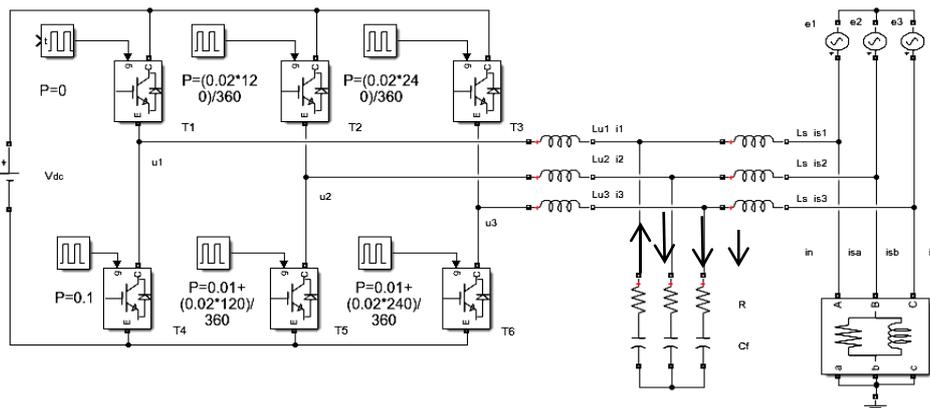


Fig.1: Three-Level overview passively damping LCL filters

1 Analysis of LCL Filter

The active countervailing of the RC branch continuously analyzes the current is wavelength form in each of the 3 phases. it deduces the out-of-phase harmonic spectrum made up of the fundamental of each harmonic. the trim

manufactures a waves that result from the difference between the current in the load and the fundamental. This wavelength is the sum of 180 degree out-of-phase harmonic currents that is then supplied to the load.

The polluting charge absorbs a current made up of a

fundamental component and harmonic components. The purpose of passive filtering is the generation of harmonic currents of the same amplitude but in phase opposition to those absorbed by the load. Thus, the current absorbed to the network will be sinusoidal. It is therefore necessary to accurately identify the harmonic currents of the polluting load. The choice of the method used to isolate the harmonic component of the charge current is a determining factor in the performance of the passive filter (dynamic precision).

2 Minimizing the cost of the inductor and calculate the currents of the filter

The filter inductor results in a loss of converter output

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{e1} \\ V_{e2} \\ V_{e3} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \tag{2}$$

The homopolar component of the source voltage is not necessary, we can write then:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \tag{3}$$

Note: It should be noted that the neutral i_n current and the homopolar current i_0 are linked by the relationship below:

$$i_n = i_{sa} + i_{sb} + i_{sc} \tag{4}$$

$$i_0 = \frac{1}{\sqrt{3}}(i_{sa} + i_{sb} + i_{sc}) = \frac{1}{\sqrt{3}}i_n \tag{5}$$

In Concordia is lair, real power and imaginary power are given by the following matrix:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{6}$$

so we can write:

voltage and a gain in current and frequency. Because the converter is output voltage is limited, total induction is a deterministic constraint. However, the induction has a better performance in changing the ripple current with a larger Inducer. Given the cost, drivers should be reduced as small as possible.

The principle of the method of Real, imaginary and homo-polar instant powers is stated below to determine filtering currents [18]. These are the simple voltages and line currents of a three-phase system with homopolar, e_1, e_2, e_3 and i_{sa}, i_{sb}, i_{sc} . Concordia's transformation brings this three-phase system from 1-2-3 axes to axes α - β -0, as shown in the following two relationships:

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = \frac{1}{V_{\alpha} + V_{\beta}} \begin{bmatrix} V_{\alpha} & -V_{\beta} \\ V_{\beta} & V_{\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (7)$$

To compensate for the harmonics of the current we apply the following mode:

$$p = \tilde{p} \quad \text{and} \quad q = \tilde{q}$$

\tilde{p} and \tilde{q} Are alternative components of real and imaginary power respectively

So:

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = \frac{1}{V_{\alpha}^2 + V_{\beta}^2} \begin{bmatrix} V_{\alpha} & -V_{\beta} \\ V_{\beta} & V_{\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (8)$$

We notice from these equations that in expressions of i_{α} and i_{β} homopolar power is absent, then:

$$\dot{i}_{\alpha}^* = i_{\alpha} \quad , \quad \dot{i}_{\beta}^* = i_{\beta} \quad , \quad \text{and for homo-polars: } \dot{i}_0^* = i_0$$

Now it is easy to go back to the baseline currents by the reverse transformation of Concordia :

$$\begin{bmatrix} \dot{i}_{sa}^* \\ \dot{i}_{sb}^* \\ \dot{i}_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} \dot{i}_{\alpha}^* \\ \dot{i}_{\beta}^* \\ \dot{i}_0^* \end{bmatrix} \quad (9)$$

III. PASSIVE LCL DAMPING METHODS

In LCL filter, the resonance effect can produce instabilities at the output, especially if some harmonic voltage/current is close the resonant frequency.

To attenuate the possible resonances caused by the high-order power filter, whether an LC or an LCL filter are used the closed-loop inverter system with passive damping or active damping schemes should be adopted [19-20].

In view of the suppleness and the cost, it mainly deals with LCL filter hardware circuit itself, so that sometimes the passive damping method is more attractive than the active damping.

Notice that bandwidth is always limited so that for certain frequencies active damping may not be able to actuate. Nevertheless, it is a challenge to balance the power

losses or to have the satisfactory damping effect and to have the harmonic attenuation when selecting the damping parameters for a high order power filter [21]. Passive damping is achieved by adding a resistance in series or in parallel with the capacitance as presented in next subsections.

The purpose of using damping is to reduce the value of resonance frequency. It is often easy to achieve by inserting a resistance in parallel or in series with the capacitor as shown in the two figures below.

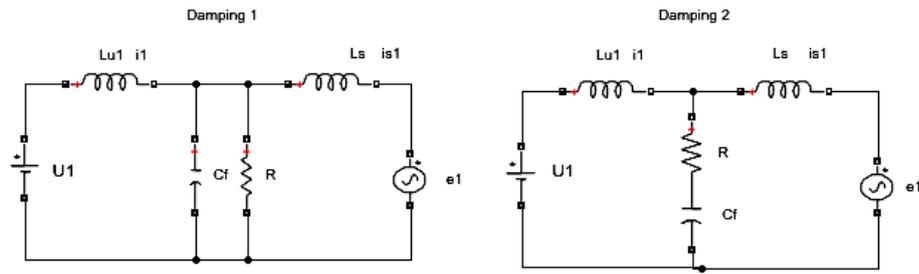


Fig. 2: damping R with C_f parallel (damping 1) ; damping R with C_f series (damping 2)

The damped R in LCL filter is inserting to have the resonance, we can write this equation :

$$\frac{1}{2\pi} \sqrt{\frac{L_{u1} + L_{us}}{L_{u1} L_s C_f}} \quad (10)$$

1 Maximize Attenuation of Switching Frequency Current

As is shown in Figure 2, The transfer function $G_{1i}(s)$ related to the converter output voltage u_1 and converter current i_1 , $G_{2i}(s)$, the transfer from u_1 to grid current; $H_{21}(s)$, the transfer from i_1 to i_2 , can be described as:

$$G_1(s) = \frac{i_{e1}}{U_1} = \frac{\left(\frac{1}{L_{u1}}\right)(s^2 + \frac{1}{L_{u1}C_f})}{s(s^2 + \frac{L_{u1} + L_s}{L_{u1}L_sC_f})} \quad (11)$$

$$G_{2is1}(s) = \frac{1}{s(s^2 + \frac{L_{u1} + L_s}{L_{u1}L_sC_s})} \quad (12)$$

$$H_{21}(s) = \frac{i_1}{i_{s1}} = \frac{1}{s^2 + \frac{1}{L_sC_f}} \quad (13)$$

The transfer function of converter side inductor from voltage to current is: $G_1(s) = 1/L_{u1}(s)$. As is shown in Figure 2, $G_{2i_{s1}}(s)$ and $H_{21}(s)$ have the same amplitude and frequency characteristics after the resonant frequency. For high frequency switching ripple current, $G_1(s) \approx 1/L_{u1}(s)$, it is extremely important to choose an appropriate converter side inductor L_1 . From the view of circuit, for high frequency current, filter capacitor C is equivalent to short-circuited.

The switching frequency ripple current is determined by L_{u1} . Therefore, the inhibition of ripple current is the first issue to be considered when designing the converter side

inductor L_{u1} .

The LCL filter transfer functions of line side current and inverter input voltage in a grid-connected mode of operation with series and parallel damping resistance are given in equations (11) and (12) respectively. From the transfer functions, by analyzing those equations, larger series resistance values can give better damping, as can be seen from the transfer functions after damping in equation (13).

2 Representation of the simulation results

Parameters of damping LCL filter

parameters	Values
$L_s/\mu H$	143
$L_{d1}/\mu H$	540
$C_f/\mu F$	115
R/Ω	0.5
Frequency (Hz)	50
F_s (Switchingfrequency) KHz	3
Voltages V	650/220

Tab. 1: Parameters of damping LCL filter

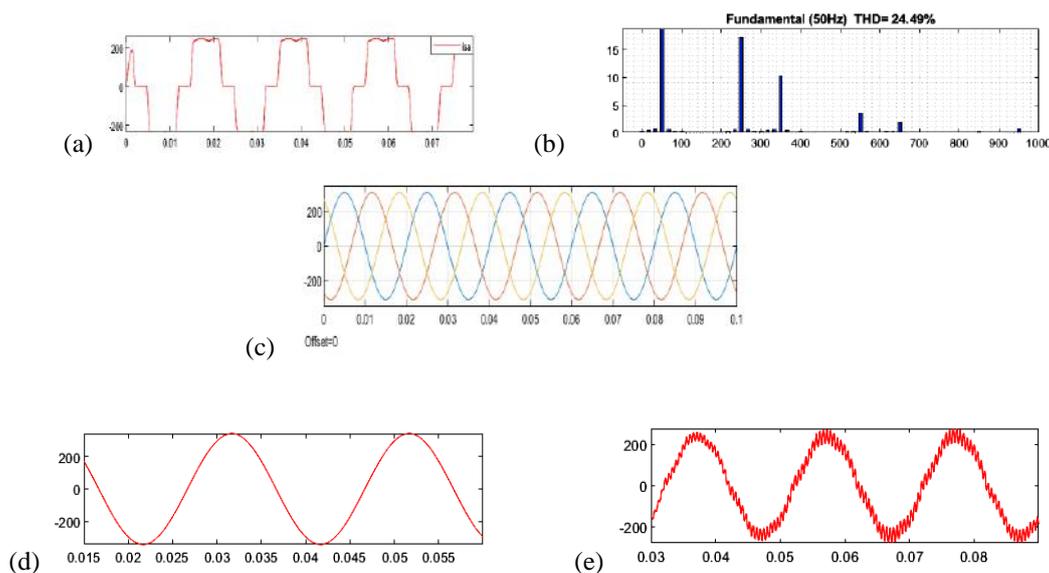


Fig. 3: Harmonic Waveform (a),(b),(c),(d),(e) of LCL Filter

Fig. 3: (a) shows load current i_{sa}^* whereas Fig. (b) is illustrated that THD of 24.49% is measurable when damping resistance is connected in parallel with LCL filter. It is proved that, the parallel resistance is the bridge effected arrangement, at the inverter-grid connection where this R will help to increase the time constant of the filter. Fig. (c) Show entrance voltage.

The current waveform without damping resistance is high THD due to non-quality signal that is effected on the inductor-capacitor. However, current waveform after filler by LCL filter with the combination of the R has improve the quality of the signal as shown in Fig. 3: (d).

IV. CONCLUSION

In this article, we have presented compensation solutions for this harmonic pollution. Several traditional

and modern clean-up solutions were presented. we have shown that the classic solution based on passive filters is often penalized in terms of clutter and resonance. On the other hand, the use of parallel active filters and series with their combinations presents itself as the best solution to date for all types of disturbances that may appear in the electrical grid.

REFERENCES

- [1] Reznik A, Simoes M G, Al-Durra A, et al. LCL filter design and performance analysis for small wind turbine systems[C]//Power Electronics and Machines in Wind Applications, Denver, USA, 2012: 1-7.
- [2] Yang Renzeng, Zhang Guangxian. Nonlinear damping controller for grid-connected LCL filters. Transactions of China Electrotechnical Society, 2015, 30 (24): 152-159.
- [3] Jovcic D, Zhang Lu, Hajjan M. LCL VSC converter for

- high-power applications[J]. IEEE Transactions on Power Delivery, 2013, 28(1): 137-144.
- [4] Chen Yun, Liu Fei. Design and control for three- phase grid-connected photovoltaic inverter with LCL filter[C]//IEEE Circuits and Systems International Conference on Testing and Diagnosis, Chengdu, China, 2009: 1-4.
- [5] NEAGU, C. BOGDAN, GRIGORA, GHEORGHE, and SCARLATAACHE, Florina. The influence of harmonics on power losses in urban distribution networks. In: Fundamentals of Electrical Engineering (ISFEE), 2016 International Symposium on. IEEE, (2016) 1 - 4 p.
- [6] Huang Yafeng, Li Long, Yan Gangui, et al. Parameter optimization design for LCL filter of large capacity PV inverter[J]. Power System Protection and Control, 2013,41(21): 104-109.Park M Y, Chi M H, Park J H, et al.
- [7] LCL-filter design for grid-connected PCS using total total harmonic and ripple at ripple tenuation factors//Power Electronics Conference, Sapporo, Japan, 2010: 1688- 1694.
- [8] Zeng Guohong, Rasmussen T W, Teodorescu R. A novel optimized LCL-filter designing method for grid connected to the network erd //2nd IEEE International Symposium on Power E lectronics for Distributed Generation Systems, Hefei, China, 2010.
- [9] Lee K J, Park N, Kim R Y, et al. Design of an LCL filter employing a symmetric geometry and its control in grid-connected inverter applications[C]//Power Electronics Specialists Conference, Rhodes, Australia, 2008: 963-966.
- [10] Liu Fei, Zha Xiaoming, Yan Zhou, et al. Design and research on parameter of LCL filter in three-phase grid-connected inverter[J]//IEEE International Power Electronics and Motion Control Conference, Wuhan, China, 2009, 25(3): 2174-2177.
- [11] Li Jianquan, Wu Xiaoyun, He Xingyao, et al. Research on the active power damping control of LCL-APF based on concentrated compensation[J]. Power System Protection and Control, 2015, 43(5): 101-106.
- [12] Liu Fei, Zha Xiaoming, Duan Shanxu. Design and research on parameter of LCL filter in three-phase grid-connected inverter[J]. Transactions of China Electrotechnical Society, 2010, 25(3): 110-116.
- [13] Wu Jian, Ma Xiao, Hou Rui, et al. Optimization of APF LCL output filter based on genetic algorithm[J]. Transactions of China Electrotechnical Society, 2011, 26(5): 159-164.
- [14] M. Liserre, F. Blaabjerg, and S. Hansen, "Design and control of an LCL filter-based three-phase active rectifier," IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1281-1291, Sept./Oct. 2005.
- [15] W. Li, X. Ruan, D. Pan, and X. Wang, "Full-feedforward schemes of grid voltages for a three-phase LCL-type grid-connected inverter," IEEE Trans. Ind. Electron., vol. 60, no. 6, pp. 2237-2250, Jun. 2013.
- [16] Liu Qian, Peng Li, Tang Shiyang, et al. A design and optimization method of LCL filters based on the graphic-analysis[J]. Proceedings of the CSEE, 2012, 32(36): 36-43.
- [17] Wang Yaoqiang, Wu Fengjiang, Sun Li, et al. Opti mized design of LCL filter for minimal damping power loss[J]. Proceedings of the CSEE, 2010, 30(27): 90-95.
- [18] Julean, A. (2009). Active damping of LCL filter resonance in grid connected applications. Aalborg Universitet, Dinamarca, Dissertação de mestrado.
- [19] H. AKAGI, « Active Harmonie Filters », IEEE, vol. 93, n°12, p. 2128-2141, 2005.
- [20] Wu, W. He., Y., Tang, T., & Blaabjerg, F. (2013). A new design method for the passive damped LCL and LLCL filter-based single-phase grid-tied inverter. IEEE Transactions on Industrial Electronis, 60(10), 4339-4350.
- [21] Renzhong, X., Lie, X., Junjun, Z., & Jie, D. (2013). Design and research on the LCL filter in three-phase PV grid-connected inverters. International Journal of Computer and Electrical Engineering, 5(3), 322.