SPREAD OF HIGH FREQUENCY CURRENT EMISSION

Math BOLLEN Hossein HOOSHYAR Sarah RÖNNBERG
Luleå University of Technology – Sweden
math.bollen@ltu.se hossein.hooshyar@ltu.se sarah.ronnberg@ltu.se

ABSTRACT

This paper investigates the spread of the high frequency current emission between devices of different size and the grid. The impact of the EMC filter, either LCL or CLC configuration, has been considered from a simplified model. The high frequency current emission, produced by a large device, can potentially cause a relatively large current flowing through a nearby small device. An important conclusion from the study is that current amplification can occur due to harmonic resonances between different types of filters.

INTRODUCTION

Power electronics is being increasingly employed in end-user equipments such as active power factor correction (APFC) in fluorescent lamps ballasts. An EMC filter of either CLC or LCL is present on the grid-side of the power electronic switching devices to limit the high frequency emission into the grid [1].

When a large number of these devices are connected at the same location, the interaction between the devices of different sizes, the high frequency emission into the grid, and the harmonic resonance, due to EMC filters and line inductors or transformer leakage inductance, are becoming of interest [2,3].

A study for the combination of multiple APFC's and the corresponding CLC EMC filters was presented at CIRED 2011 [3]. In this study, the model used in that paper has been extended to consider the different types of EMC filters and the grid impedance.

INTERACTIONS BETWEEN DEVICES OF DIFFERENT SIZE

Figure 1 illustrates the equivalent circuit for two devices of different size connected to a common node. $\vec{I}_{L1}$ and $\vec{I}_{L2}$ represent the internal emissions flowing through the inductors of the CLC filters. Also, C_1 and C_2, are the grid side capacitors of those filters. The grid is modelled by a resistance, *R*, as the resistance is dominating in low-voltage networks, especially close to the equipment. For higher frequency, *R* would be equal to the wave impedance [3].

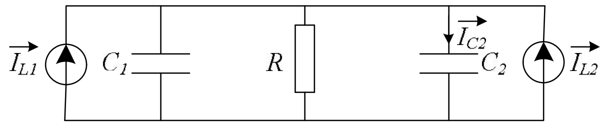

Figure 1. Two devices of different size connected in parallel to a common node.

Now, assuming that the first device is the larger one, e.g. a charger of electric cars, and the second equipment is the smaller one, e.g. an LED lamp, the current flowing through the capacitor of the smaller equipment is obtained from the following equation:

$$\vec{I}_{C2} = \frac{j\alpha_2}{1 + j(\alpha_1 + \alpha_2)}\left(\vec{I}_{L1} + \vec{I}_{L2}\right) \tag{1}$$

where $\alpha_1 = RC_1\omega$ and $\alpha_2 = RC_2\omega$.

Considering that $\left|\vec{I}_{L2}\right| << \left|\vec{I}_{L1}\right|$, the magnitude of $\vec{I}_{C2}$ can be approximated for high frequencies (α_1 and α_2 large) as:

$$I_{C2} = \frac{\alpha_2}{\sqrt{1 + (\alpha_1 + \alpha_2)^2}} I_{L1} \overset{for\,\alpha_i >> 1}{\Rightarrow} \\ I_{C2} = \frac{\alpha_2}{\alpha_1 + \alpha_2} I_{L1} \tag{2}$$

Considering (2), it can be concluded that the high frequency current emission, produced by a large device, can potentially cause a relatively large current flowing through a nearby small device. However this can be prevented if the method of dimensioning the EMC filter considers a relation between the capacitor size and the current emission at high frequency.

HARMONIC RESONANCES OF EMC FILTERS AND LINE INDUCTANCE

Harmonic resonances can occur due to EMC filters with power electronic devices and the leakage inductances of the transformers or inductors installed in the distribution feeders.

The harmonic resonances have been investigated in two separate parts, one considering just one device, and the other one considering multiple devices connected to the grid at the same location.

Single device

Figure 2 shows the equivalent circuit of a single device connected to the grid. The inductance, *L*, represents the inductive part of the source impedance at the point of connection of the device to the grid .

The current flowing out of the equipment and into the grid, $\vec{I}_{grid}$, can be obtained from the following equation:

$$\vec{I}_{grid} = \frac{1}{(1-\beta)+j\alpha}\vec{I}_L \tag{3}$$

where $\alpha = RC\omega$ and $\beta = LC\omega^2$.

The magnitude of $\vec{I}_{grid}$ can be expressed as:

$$I_{grid} = \frac{1}{\sqrt{(1-\beta)^2+\alpha^2}} I_L \tag{4}$$

Figure 3 illustrates I_{grid} versus ω. As shown in the figure, the maximum value of I_{grid} occurs close to $\omega = 1/\sqrt{LC}$ and is approximately equal to $I_{grid}^{\max} = \frac{\sqrt{L/C}}{R} I_L$. Note that there will be an amplification (I_{grid} becomes larger than I_L) when the resistance is smaller than the characteristic impedance of the resonance circuit ($R < \sqrt{L/C}$).

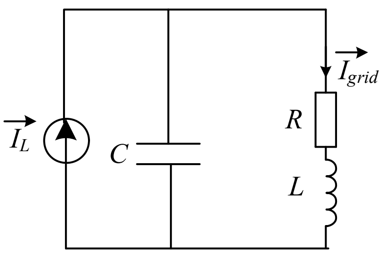

Figure 2. Single device connected to the grid.

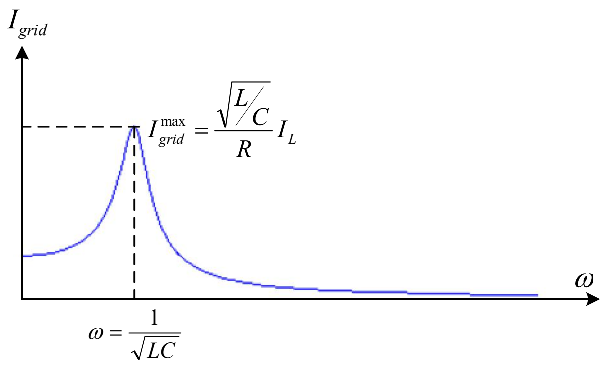

Figure 3. High frequency current emission from a single device connected to the grid.

Multiple devices

Similar equations can be obtained for multiple devices connected to the grid at the same location, as illustrated in Figure 4. The high frequency current emitted from *N* number of devices to the grid can be expressed as:

$$\vec{I}_{grid} = \frac{N}{(1-N\beta)+jN\alpha}\vec{I}_L \Rightarrow \tag{5}$$

$$I_{grid} = \frac{N}{\sqrt{(1-N\beta)^2+(N\alpha)^2}} I_L \tag{6}$$

As illustrated in Figure 5, the maximum value of I_{grid} occurs close to $\omega = 1/\sqrt{NLC}$ and is approximately equal to $I_{grid}^{\max} = \sqrt{N}\frac{\sqrt{L/C}}{R} I_L$. It's worth noting that, as Figure 5 indicates, the current amplification rises proportionally to the square root of the number of connected devices ($\sqrt{N}$) while the resonance frequency drops with the same rate. As an example, Figure 6, obtained based on realistic data, shows the ratio of the current emission flowing into the grid over the internal current emission of individual devices versus frequency for different number of similar devices connected at the same location. As the figure shows, a strong amplification can occur due to harmonic resonances. With an increasing number of devices, the resonance frequency drops and the amplification increases.

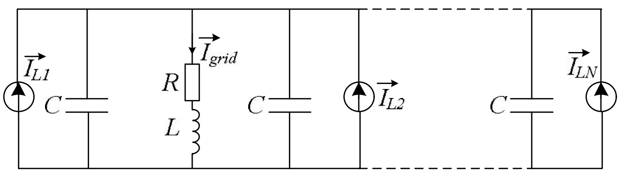

Figure 4. N number of devices connected to the grid.

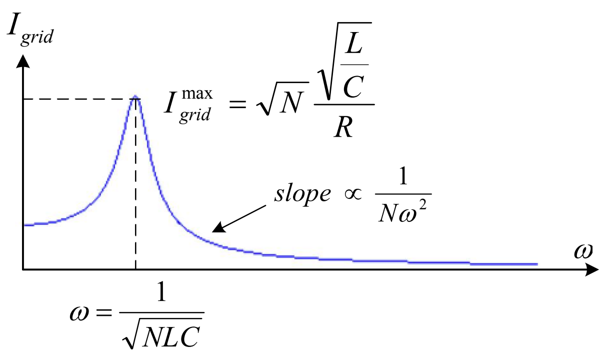

Figure 5. High frequency current emission from multiple devices connected to the grid.

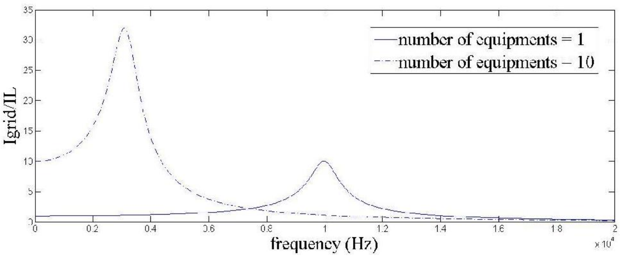

Figure 6. Ratio between the current flowing into the grid and the internal emission (on converter side of the EMC filter) from one device, as a function of frequency.

INTERACTION OF CLC AND LCL FILTERS

The spread of high frequency current emission among devices with a combination of CLC and LCL EMC filters and also the condition under which the harmonic resonance occurs in such circuits have been studied as well.

This interaction has again been studied in two separate parts, one considering just a single device from each filter type, and the other one considering multiple devices from each filter type connected to the grid at the same location.

Single device of each filter type

Figure 7 shows the equivalent circuit for two devices, one from the CLC type and the other one from the LCL type, connected to a common node. $\vec{I}_{Lb}$ represents the internal emissions flowing through the inductor of the LCL filter. Also, C_b and L_b, are the other components of the LCL filter. Equations (7) to (9) express the emissions flowing out of the CLC filter, flowing out of the LCL filter, and flowing into the grid, respectively.

$$\vec{I}_{CLC} = \frac{[(1-\beta)+j\alpha_b]\vec{I}_{La} - j\alpha_a\vec{I}_{Lb}}{(1-\beta)+j(\alpha_a+\alpha_b-\alpha_a\beta)} \quad (7)$$

$$\vec{I}_{LCL} = \frac{-j\alpha_b\vec{I}_{La} + (1+j\alpha_a)\vec{I}_{Lb}}{(1-\beta)+j(\alpha_a+\alpha_b-\alpha_a\beta)} \quad (8)$$

$$\vec{I}_{grid} = \frac{(1-\beta)\vec{I}_{La} + \vec{I}_{Lb}}{(1-\beta)+j(\alpha_a+\alpha_b-\alpha_a\beta)} \quad (9)$$

where $\alpha_a = RC_a\omega$, $\alpha_b = RC_b\omega$ and $\beta = L_bC_b\omega^2$.

Now, assuming that $\vec{I}_{La} \approx \vec{I}_{Lb} = \vec{I}_L$, the magnitudes of these emissions can be expressed by (10) to (12), as follows.

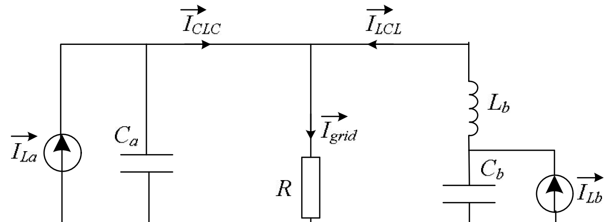

Figure 7. The equivalent circuit for two devices, one from the CLC type and the other one from the LCL type, connected to a common node.

$$I_{CLC} = \sqrt{\frac{(1-\beta)^2 + (\alpha_a-\alpha_b)^2}{(1-\beta)^2 + (\alpha_a+\alpha_b-\alpha_a\beta)^2}}\, I_L \quad (10)$$

$$I_{LCL} = \sqrt{\frac{1 + (\alpha_a-\alpha_b)^2}{(1-\beta)^2 + (\alpha_a+\alpha_b-\alpha_a\beta)^2}}\, I_L \quad (11)$$

$$I_{grid} = \frac{|2-\beta|}{\sqrt{(1-\beta)^2 + (\alpha_a+\alpha_b-\alpha_a\beta)^2}}\, I_L \quad (12)$$

These equations are discussed in more details in the next section.

Multiple devices of each filter type

Figure 8 shows the equivalent of multiple devices from each filter type connected to the grid at the same location. Following the same logic, the magnitudes of the emissions flowing out of each individual CLC filter, flowing out of each individual LCL filter, and flowing into the grid can be obtained through (13) to (15).

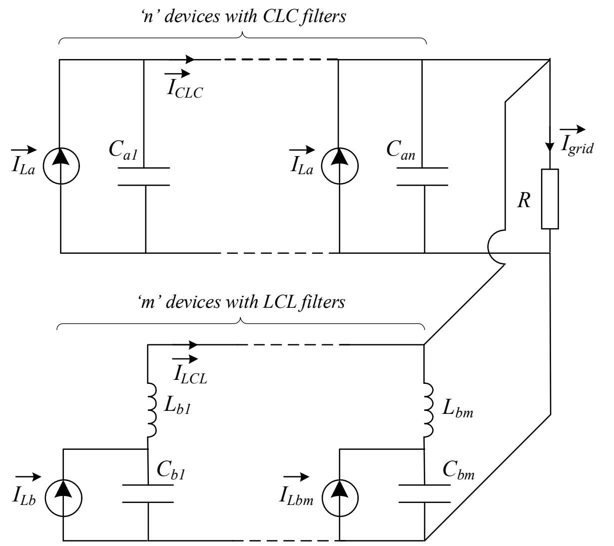

Figure 8. The equivalent circuit for two devices, one from the CLC type and the other one from the LCL type, connected in parallel to a common node.

$$I_{CLC} = \sqrt{\frac{(1-\beta)^2 + (n\alpha_a - m\alpha_b)^2}{(1-\beta)^2 + (n\alpha_a + m\alpha_b - n\alpha_a\beta)^2}} I_L \quad (13)$$

$$I_{LCL} = \sqrt{\frac{1 + (n\alpha_a - m\alpha_b)^2}{(1-\beta)^2 + (n\alpha_a + m\alpha_b - n\alpha_a\beta)^2}} I_L \quad (14)$$

$$I_{grid} = \frac{|n + m - \beta|}{\sqrt{(1-\beta)^2 + (n\alpha_a + m\alpha_b - n\alpha_a\beta)^2}} I_L \quad (15)$$

Considering (10) to (15), Figures 9 to 11 depict the magnitudes of the above-mentioned emissions versus frequency for different number of devices, based on realistic data. As shown in the figures, the high frequency emissions become noticeable for a larger range of frequency as the number of devices increases.

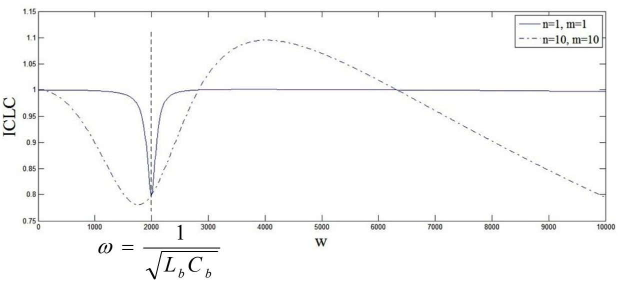

Figure 9. The magnitude of the emission flowing out of each individual CLC filter.

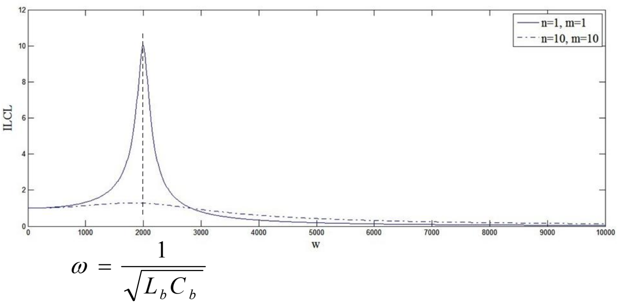

Figure 10. The magnitude of the emission flowing out of each individual LCL filter.

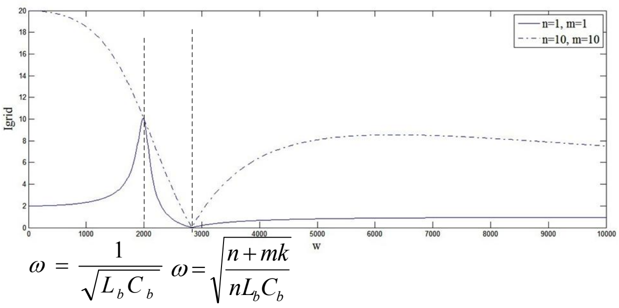

Figure 11. The magnitude of the emission flowing into the grid.

CONCLUSIONS

This paper investigates the spread of the high frequency current emission between devices of different size and the grid. The impact of the EMC filter, either LCL or CLC configuration has been considered from a simplified model.

The high frequency current emission, produced by a large device such as an electric car charger, can potentially cause a relatively large current flowing through a nearby small device, such as an LED lamp, with damage to the LED lamp as a possible consequence. However this can be prevented if the method of dimensioning the EMC filter considers a relation between the capacitor size and the current emission.

Also, the conditions, under which the harmonic resonances occur due to the EMC filters of devices connected at the same location and the grid inductance, have been identified in this study. It has been shown that the current amplification rises proportionally to the square root of the number of connected devices while the resonance frequency drops with the same rate.

The spread of high frequency current emission among devices with a combination of CLC and LCL EMC filters has been studied as well. Also here the conclusion is that current amplification can occur due to harmonic resonances.

Further studies, simulations as well as measurements, are needed to further quantify the phenomena discussed in this paper. Especially the risk of current amplification due to resonances needs to be studied.

REFERENCES

[1] E.O.A. Larsson, M.H.J. Bollen, M.G. Wahlberg, C.M. Lundmark, S.K. Rönnberg, July 2010, " Measurements of high frequency (2–150 kHz) distortion in low-voltage networks", *IEEE Trans. Pwr. Del.* vol. 25, no. 3, 1749-1757.

[2] T. Lee, Oct. 2008, "A harmonic damping method for a loop power system", *Proceedings IEEE Industry Applications Society Annual Meeting*, 1-8.

[3] S. Rönnberg, A. Larsson, M. Bollen, J. Schanen, Jun. 2011, "A simple model for interaction between equipment at a frequency of some tens of kHz", *Proceedings 21st CIRED International Conference on Electricity Distribution*, 1-4.